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A WASTE TREATMENT SYSTEM FOR CONFINED HOG RAISING OPERATIONS

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Installation cost for the system was $12,000. Net operating costs, including amortization of capital costs, were $7.33 per day. Thus, total environmental control was achieved at a cost of approximately $1.00 per hog, or 1/2 cent per pound (1.1 cent per kilogram) of weight gained while on the feeding floor. (EPA)

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ABSTRACT

A waste treatment system was installed in conjunction with an existing confined swine feeding operation at Schuster Farms, Gower, Missouri. The system consisted of a concrete aeration tank equipped with mechanical surface aerators, followed by a settling pond. Wastes from the 1,000-hog feeding operation were flushed through a gutter in the concrete feeding floor into the aeration tank, where they were aerobically digested. All aeration tank discharges were retained in the settling pond where the liquids evaporated.

The waste treatment facility operated continuously and dependably over a 2-year period, with treatment efficiency averaging 90% to 95%. The system effectively controlled objectionable odors and insects, contained all liquid runoff emanating from the feeding operation, and left only a dry, inert residue suitable for land disposal.

Installation cost for the system was $12,000. Net operating costs, including amortization of capital costs, were $7.33 per day. Thus, total environmental control was achieved at a cost of approximately $1.00 per hog, or 1/2 cent per pound (1.1 cent per kilogram) of weight gained while on the feeding floor.

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ACKNOWLEDGMENTS

This demonstration swine waste treatment system was built and operated at Schuster Farms, Gower, Missouri. The farm is owned and operated by Mr. Lee R. Schuster. Funds for the demonstration were provided in part by the U.S. Environmental Protection Agency, under Project 13040 EVM. Mr. Ronald R. Ritter, Chief of Grants Administration, Region VI, Environmental Protection Agency, served as Project Officer.

In addition to Mr. Schuster, Mr. Gary Ellington and Mr. Don Farr of Schuster Farms assisted in operation and evaluation of the waste treatment system.

Technical aspects of the operation, including specification of design and operating characteristics, startup and testing of equipment, performance monitoring, and evaluation of system performance were the responsibility of Midwest Research Institute. The Midwest Research Institute program was directed by Mr. William R. Park, P.E. Dr. Ross McKinney, University of Kansas, and Dr. William Garner, formerly of MRI and presently of the U.S. Environmental Protection Agency, assisted in system design.

SECTION I

SUMMARY AND CONCLUSIONS

The project described in this report was undertaken to demonstrate the feasibility and effectiveness of a swine waste treatment concept suitable for use with existing confined feeding operations. The demonstration was conducted at Schuster Farms, Gower, Missouri. The demonstration site was Schuster's Feeding Floor No. 7, a 70 ft by 220 ft (21 m by 67 m) partially enclosed concrete floor, having a capacity of 1,000 feeder pigs ranging in size from 30 to 225 lb (14 to 102 kg).

The heart of the treatment system consists of a 20 ft x 40 ft x 13 ft (6.1 m x 12.2 m x 4.0 m) deep reinforced concrete aeration tank equipped with two 7.5 hp bridge-mounted, gear-driven, mechanical surface aerators.

Wastes are scraped from the concrete feeding floor into a gutter, where they are flushed down into the aeration tank with water drawn from a nearby pond.

Biological reactions in the aeration tank convert some 90% to 95% of the organic wastes into water, bacterial cells and harmless gases. Any overflow from the tank is retained in a 75 ft x 125 ft (23 m x 38 m) settling basin where liquids evaporate, leaving only an inert, odorless, humus-like granular residue which can harmlessly, even beneficially, be returned to the environment via land spreading.

The total cost of the system was $12,000. Annual costs, including both capital charges (depreciation, interest, etc.) and operating expenses (chiefly electric power), were $11.62/day, lowered to a net cost of $7.33/day by the labor savings made possible by reduced manure handling. This amounts to roughly $1.00 per hog, or 1/2 cent per pound (1.1 cent per kg) of weight gained while on the feeding floor, an amount that must eventually be passed on to the pork consumer at the retail level.

This demonstration waste management system, in summary, provides for total environmental control--of liquid runoff, odors, and solid wastes--at a cost that should be acceptable to both pork producers and pork consumers.

SECTION II

INTRODUCTION

THE PROBLEM

As every feedlot operator knows, the handling and disposal of pig manure can be a real problem in a large-scale swine operation. Traditional waste disposal practices have frequently led to lawsuits and/or large expenditures for labor, equipment, and facilities; and even with substantial investments, in many cases control practices have failed to achieve the expected results in terms of solving air, water and solid waste pollutional problems.

While the environment can assimilate small quantities of raw pig manure, large amounts of this pollutant can have disastrous effects. During periods of intensive rainfall, great quantities may wash into receiving waters. This in itself is serious enough; but, unfortunately, the possibility that these contaminants may reach an otherwise unimpaired watercourse has greatly increased as a consequence of recent changes in the scale of hog raising operations.

In the past, hog growing operations have presented relatively few problems from a water pollution standpoint. Hog raising has traditionally been carried out on a small scale, and since it has been a widely scattered activity, the raw manure could be left on the land without posing any serious environmental threat. Hog raising is, in fact, still a widely scattered activity, although a definite trend toward confined feeding is becoming increasingly evident.

In the future, more and more hogs are certain to be raised in confinement. This trend will result in far greater quantities and concentrations of wastes than have yet been encountered, with the accompanying possibility of serious health hazards and costly stream pollution unless the wastes are stabilized in an environmentally acceptable manner.

Large quantities of raw pig manure are extremely objectionable even when large land areas are available for their disposal. However, hog wastes are readily biodegradable, and their stabilization can be accomplished effectively by means of relatively simple and inexpensive biological treatment systems.

The effectiveness of aerobic stabilization of hog wastes has been demonstrated in confined hog raising operations that employ slotted concrete

floors. The defecated material passes through the slots into an oxidation pit below, where aerobic digestion takes place.

The slotted-floor concept, while proven effective in newly constructed facilities, cannot easily be adapted to existing operations. Therefore, a real need exists for an economical waste treatment system that can be employed in conjunction with established hog raising operations.

As in cattle feeding, mush and wetness in the hog pens are an economic liability. Foot rot and other diseases are a direct result of dampness, while the energy expended by the animal working through mush or across slick concrete floors detracts from the weight-building body processes. For this reason, concrete-floored animal pens are scraped clean rather than flushed clean. Hydraulic cleaning and carriage of manures may seem attractive from a sanitary engineering viewpoint, but the attendant wetness in the pens would be most objectionable for the hog raiser.

The problem, then, is to stabilize large quantities of a highly putrescible semisolid and thus eliminate the potential of stream deterioration from this material.

Because of the physical nature of the manure, it defies composting. Anaerobic digestion is both difficult to control and aesthetically objectionable. Thus, the desired restraints on the system are:

1. Mechanical cleaning of the pens;

2. Mechanical or hydraulic movement of the manure to a treatment site.

3. Aerobic-liquid stabilization;

4. Separation of the stabilized solids; and

5. Dispersal of the stabilized solids on adjacent croplands.

As in any waste disposal problem, the ideal solution would be to achieve complete recycling of all materials--in effect, a "closed-loop" system. For example, cropland produces grains used in feed for hogs; each 3 unit weights of feed results in roughly 1 unit weight gain and 2 unit weights of waste material. The waste material can then be collected and distributed on the cropland as fertilizer to grow more grain to feed more hogs and produce more waste. Thus, the cycle could continue almost indefinitely.

However, this situation, while possible, is not economically feasible. The scale of hog raising operations, the economy and convenience of chemical fertilizers, and the use of processed and concentrated feeds have all combined to decrease the relative economic value of hog manure as a soil nutrient. However, while the potential for economic reuse of hog manure is negligible, its potential for polluting nearby streams is increasing rapidly as disposal goes on as cheaply as possible--usually by dumping without regard to possible effects on water quality.

The overall problem of returning hog wastes to the environment in a nonpollutional and environmentally acceptable manner can be divided generally into three phases: (1) collection; (2) stabilization; and (3) disposal.

The collection phase is by far the simplest, although it offers a number of interesting possibilities. Except in new installations utilizing the slotted-floor concept, mechanical cleaning of pens is generally required, for the reasons previously cited. Existing facilities, where hogs are confined outdoors on concrete slabs, usually involve scraping the manure from the floor, either mechanically or manually, and dumping it downwind or downstream. If a waste-stabilization facility were available, the manure could be dumped in it with perhaps even greater convenience. Or, a system of open collection sewers or lined trenches could be installed inexpensively, so that material scraped from pens could be directed into the trenches and carried hydraulically to the central treatment facility; the water used for transporting the wastes could be drawn from either a pond or from the treatment facility itself. Such is the waste collection system developed for the demonstration project.

For stabilization of swine wastes, aerobic biological waste treatment systems have proven to be effective. However, many of the systems currently in use are suitable only for newly constructed facilities. In some of these, the hog confinement area is, in effect, built around or over the waste treatment plant.

The primary interest of the hog raiser, however, is in raising hogs and not in treating hog wastes. An acceptable treatment system must recognize this fact and offer the operator a convenient and economical means of handling the substantial quantities of waste material generated by the confined hogs.

Only when disposal by means of treatment becomes more advantageous to the hog raiser than disposal of the raw wastes--that is, when there is a proven, direct, measurable economic benefit accruing to the operator

from the waste treatment process--will such treatment become an accepted part of the hog raising business.

THE SOLUTION

Schuster Farms initiated the extensive pollution control program described in this report. This waste management system solves many of the costly environmental problems commonly associated with confined feeding operations. The program, incorporating waste handling, treatment and disposal operations, virtually eliminates all pollutional threats to the surrounding land, air and water.

The project involved a three-way cooperative effort between Schuster Farms, Midwest Research Institute (MRI), and the Environmental Protection Agency (EPA). The system design, monitoring and evaluation were MRI's responsibility; Schuster Farms built and operated it; and the demonstration project was partially financed by EPA.

The demonstration project was carried out at Schuster Farms, located in Gower, Missouri. The hog feeding operations are located on Missouri State Road DD, about 50 (80 km) north of Kansas City.

Schuster Farms has one of the largest integrated (farrowing and finishing) swine facilities in the United States, with yearly sales of 15,000 butcher hogs. At full capacity, there are ample facilities for 1,600 sows, 1,500 pigs in weaning pens, and 7,000 hogs in finishing pens, with 300 farrowing beds and parlors housing 1,600 pigs.

The demonstration system described herein has been designed, constructed and operated to accommodate the wastes from hogs of known characteristics, confined in an existing building housing from 700 to 1,000 feeder pigs.

The treatment facility consists of a separate, outside, aerobic biological system, capable of producing a biologically stabilized effluent from raw hog wastes. This system is readily adaptable to both existing and new hog raising operations.

Because of the restraints on system design and since the effectiveness of aerobic biological treatment of hog wastes has already been proven, this type of system was selected for the demonstration. In order to conserve space and, at the same time, to provide a relatively high degree of treatment at minimal cost, a surface-aerated complete mixing activated sludge system was employed.

This approach offers several distinct advantages over the more conventional slotted-floor, oxidation ditch concept.

1. It can be used with existing confined hog feeding operations, as well as with newly constructed facilities.

2. It avoids the additional cost of slotted concrete floors (approximately $1.10 per square foot ($11.84/m^2) more than smooth floors), thus reducing the total cost of confined feeding and waste treatment operations.

3. A single treatment facility can be sized to treat wastes from a number of different buildings, thus affording economies of scale and eliminating the necessity for having several small, separate treatment systems.

4. Maintenance problems are significantly reduced by having fewer, more readily accessible parts requiring repair or replacement.

The demonstration project described in this report was carried out in several distinct phases:

1. The engineering phase, which included actual laying out of the demonstration site; detailed system design in view of the effluent requirements; construction; and startup.

2. The operational phase, during which time the system was operated and data collected. Samples were taken periodically at various points in the system, over a 1-year period. At the same time, pertinent economic data were compiled, including the costs of operation and maintenance and all other expenses incurred in handling and disposing of the wastes.

3. The analysis phase, wherein the collected data were analyzed, guidelines for future use were developed, and the results of the project were carefully documented--both from a technical and economic viewpoint.

The entire project has been result-oriented, with the primary aim of demonstrating that waste treatment can be accomplished at reasonable cost and with a minimum of inconvenience to the producer.

The success of this demonstration project is evidenced by both the results achieved at the demonstration site and by the application and adoption of the resulting knowledge and techniques to major swine operations in other areas.

In summary, it is believed that the many lessons learned in connection with this demonstration project constitute a major contribution to knowledge in the area of agricultural pollution control. The techniques developed at the Schuster Farms demonstration site will prove invaluable to farmers throughout the United States, and, properly applied, will aid in achieving the goal of improved environmental quality at minimum cost.

SECTION III

THE WASTE TREATMENT FACILITY

THE CONCEPT

The concept of the demonstration waste treatment system installed by Schuster Farms is quite simple. Figure 1 shows the general layout of the facilities involved.

The waste treatment facility consists of a concrete tank equipped with mechanical aerators. When the pens are cleaned, wastes are flushed through a gutter and into an aeration tank where biological reactions remove some 95% of the pollutants. The treated wastes flow from the tank to a small pond, where the remaining solids settle out and the liquid evaporates, leaving only an inert humus-type material for spreading on cropland as a soil conditioner.

The basic unit in the treatment system is a 20 ft x 40 ft x 13 ft deep (6.1 m x 12.2 m x 4.0 m deep) aeration tank, designed to handle the wastes from a maximum of 1,000 hogs weighing 220 lb (100 kg) each.

This aeration tank is connected to the feeding floor by an 11 in. wide x 6 in. deep (28 cm wide x 15 cm deep) gutter system that runs the entire length of the building. The building was converted from a cattle feeding barn, which shows the adaptability of this system to almost any existing facility. There are four individual pens measuring 70 ft x 55 ft (21 m x 17 m), each equipped with self-feeders and automatic waterers. Below the aeration tank is a 75 ft x 125 ft (23 m x 38 m) settling basin that catches any overflow from the tank.

The cleaning of these pens now consumes the efforts of two men for 1.5 hr every other day. The only major piece of equipment is a four-wheel-drive Melroe Bobcat front-end loader. The loader is used to scrape the manure from the pens into the gutter. The second man scrapes around the feeders and waterers with a shovel and assists the Bobcat operator. Water is pumped from a nearby pond into the gutter at a rate of about 25 to 30 gal/min (95 to 115 liters/min) in order to flush the wastes down the gutter and into the tank.

Biological reactions taking place in the aeration tank are the key to the system's effectiveness in eliminating pollution. In a properly operating aerobic waste treatment system--one where plenty of oxygen

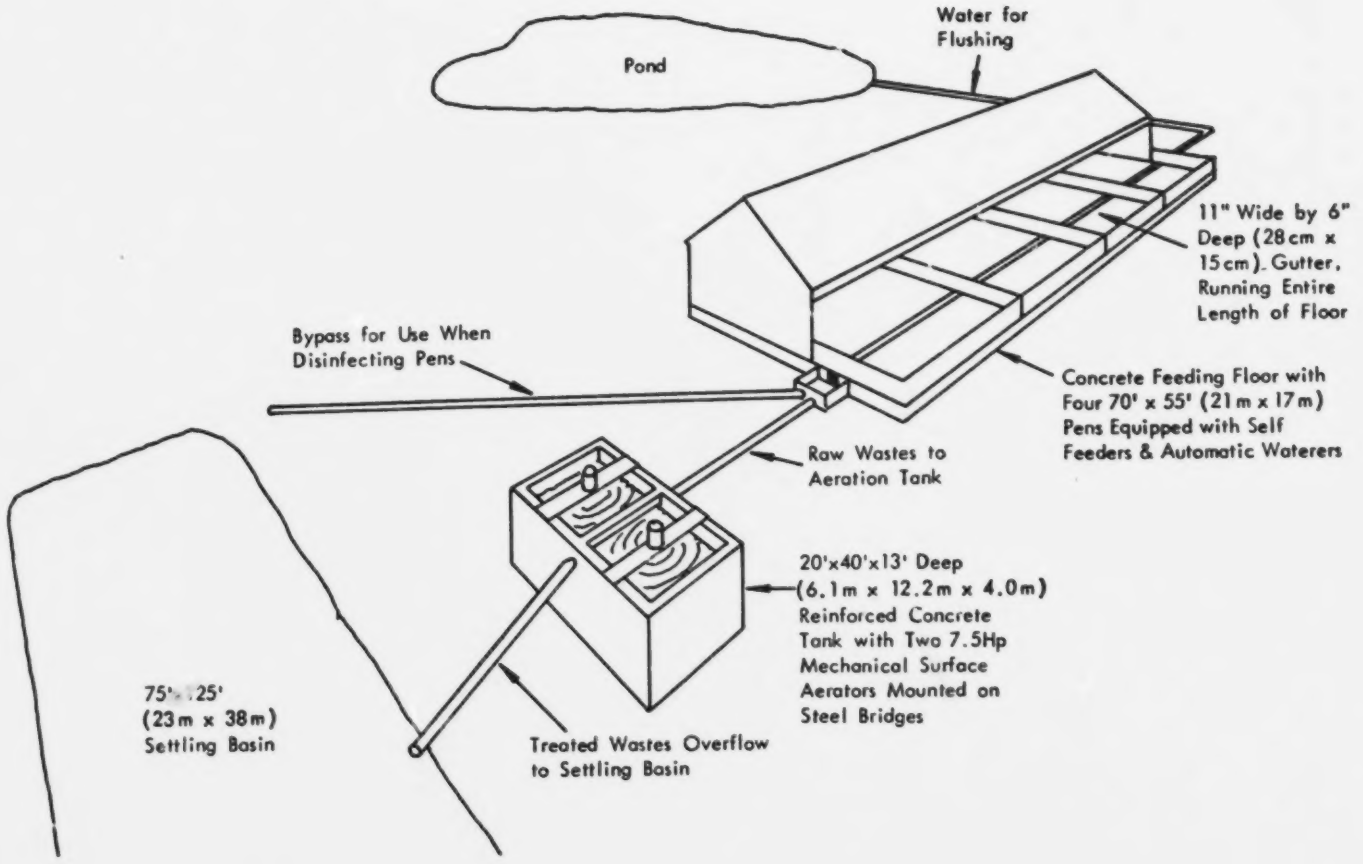

Figure 1 - Swine waste management system at Schuster Farms

is available--the wastes are eaten by bacteria and converted into bacterial cells, along with several inoffensive by-products: water (H_2O), carbon dioxide (CO_2), and ammonia (NH_3). The CO_2 and NH_3 enter the atmosphere as harmless gases, leaving only water behind. Basically, the reaction that takes place in a properly engineered waste treatment process like this is:

$$\text{Organic Wastes} + \text{Bacteria} + \text{Oxygen} = \text{More Bacteria} + H_2O + CO_2 + NH_3$$

Within an hour, these bacteria can eat more than 90% of the waste materials dumped in the tank. Then, instead of the tank being full of water and manure, it contains primarily water and bacterial cells. If the bacteria's food supply (the manure in this case) stops, the bacteria will slowly starve to death, shrinking to only about a fifth of their original mass. These dead bacterial cells form the inert humus residue from the system that ends up in the settling basin.

For these reactions to take place, it is essential that sufficient oxygen be available. Otherwise, the aerobic bacteria cannot function, and the system will turn anaerobic, or septic. Should this happen, methane and hydrogen sulfide will be generated as by-products instead of CO_2 and ammonia, and the waste will stink. This commonly happens when a rotor breaks down in an oxidation ditch beneath the slotted floor in totally confined indoor swine facilities, or when an aerated lagoon is overloaded because of poor design or inadequate aeration equipment.

MECHANICAL EQUIPMENT

A great deal of care must be exercised in selecting aeration equipment to be used in treating swine wastes. Most commercially available aerators are not designed for this type of waste, and are physically incapable of supplying oxygen at the rate required, regardless of the claims made for "oxygen transfer" by sales engineers! There are few manufacturers of aeration equipment that can effectively and economically do the job required in this type of system.

In the Schuster system, two 7.5 hp bridge-mounted mechanical surface aerators (manufactured by Smith & Loveless in Lenexa, Kansas) were installed. They run continuously, 24 hr/day, 365 days/year, to insure that there is plenty of oxygen in the tank at all times. The system design is such that a single aerator, mounted in the center of a 20 ft x 20 ft x 10 ft deep (6 m x 6 m x 3 m) module will handle the wastes

from 500 full-grown hogs. Thus, a 1,000-hog operation uses two aerators in a 20 ft x 40 ft (6 m x 12 m) tank, and a 1,500-hog operation could be easily handled just by adding another module (with an aerator) to the tank, making it 20 ft x 60 ft (6 m x 18 m); to handle the wastes from 2,000 hogs, a 20 ft x 80 ft (6 m x 24 m) or 40 ft x 40 ft (12 m x 12 m) layout could be used. Any tank configuration is acceptable, just so it is built in 20 ft x 20 ft (6 m x 6 m) modules having a 10 ft (3 m) liquid depth and an appropriate aerator mounted in the center of each module.

GENERAL ECONOMICS

The total cost of this particular system ran $12,000, of which about half was for the two aerators and bridges and the remainder was for construction of the tank and settling basin, wiring, grading, pipe, etc.

Operating costs, including electric power, maintenance, and depreciation and interest on the tank and equipment are $4,200 annually. However, savings in manure handling over the old scrape, haul and dump method previously used, amount to nearly $1,600 yearly because of the requirement for less labor and equipment, so the net additional cost of this system is actually less than $2,700/year, or $7.40/day. This is roughly 1/2 cent per pound (1.1 cent per kg) of weight gain, or $1.00 in additional costs on each hog, spread over its time spent on this feeding floor.

It must be realized, however, that even though this system is about the cheapest way to provide complete environmental control in swine raising operations, the extra dollar added to the cost of each market-ready hog represents a substantial portion of the profit in that hog. Eventually, the dollar will have to be passed on to the pork consumer as his cost of environmental protection.

ADVANTAGES TO THE FEEDLOT OPERATOR

As a direct result of implementing this program at Schuster Farms, the pen cleaning operation is now a faster, more efficient operation than before, and provides total pollution control at a cost that can at least be lived with.

The system has proven to have a number of advantages, some of which are:

1. It requires little change of existing facilities. If a gutter can be put somewhere in, or by, an existing building, this is the only structural change needed.

2. It requires a small amount of land. The tank uses a 20 ft x 40 ft (6 m x 12 m) area. A lagoon to handle the same amount of waste could require as much as 20 acres (8 hectares). This is very important when land sells for $400 or more per acre ($989 per hectare).

3. Cleaning can be done in any weather or season. It is not necessary to wait until crops are out to spread, or to wait for a field to dry sufficiently so it can be driven on.

4. It requires less time, men, and equipment than a conventional system. In this case, cleaning requires an hour less than before, one less man than was used previously, and a truck, manure spreader, and tractor are no longer needed to dispose of the waste.

5. There are no mechanical parts in hard-to-service areas. With an oxidation ditch or manure drag chain, there are many moving parts in contact with manure at all times. The aeration tank has only two rotors that revolve in the top 6 ft (2 m) of the tank.

6. There is no runoff to area streams or adjoining farms. Runoff is a problem that has closed down many large-scale operations in the past.

7. There is no air pollution. There is essentially no odor from the tank; this will become increasingly important as cities expand closer to the livestock feeding areas.

8. There is no solid waste buildup. Huge waste piles serve as breeding grounds for flies and other disease carriers. Disease spreads quickly in high density populations and every control measure can mean the difference between profit and disaster.

9. The control measures employed comply with every existing federal and state law governing feedlot waste removal. With zero runoff, no odor, and no solid waste buildup, this system can pass the most stringent laws now on the books or proposed for the next 15 years concerning feedlot waste.

At a cost of 1/2 cent per pound (1.1 cent per kg) gain this system has proven to be an efficient and economical solution to Schuster Farms' waste disposal problems.

PICTORIAL DESCRIPTION OF SYSTEM OPERATION

The following 27 photographs describe the operation of the demonstration swine waste treatment facility, along with some of the problems encountered and overcome during the evolution of the system as it now functions.

Figure 2, a plan view of the general layout, shows the approximate location and direction in which each photograph was taken.

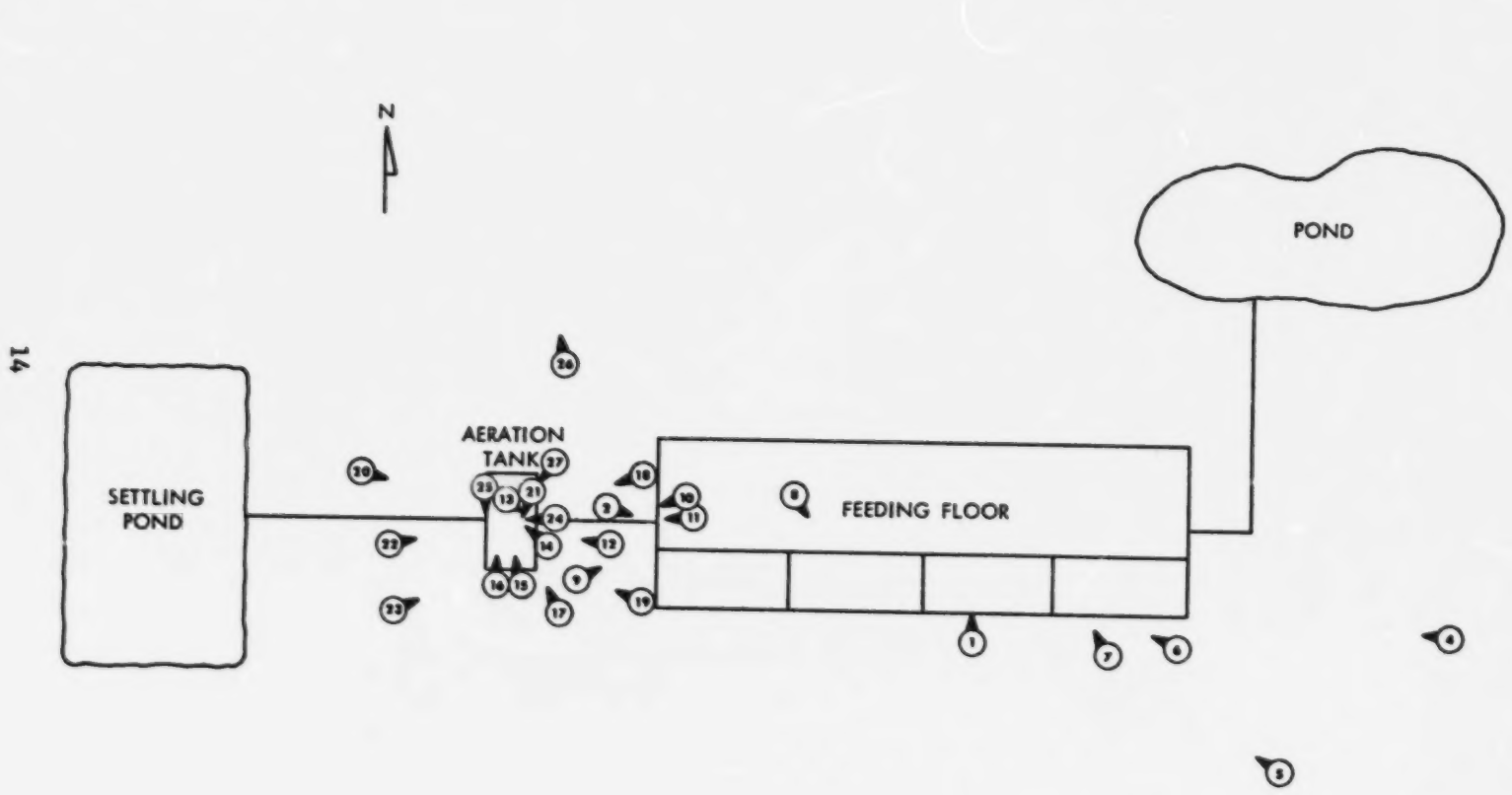

Figure 2 - Plan view of demonstration site showing location and direction of photographs

Photo 1. Herein lies the problem. A feeder pig eats between 3 lb and 3-1/2 lb (kg) of food for every pound (kilogram) of weight it gains. This means, in simple terms, that for every pound (kilogram) of pork, two or more pounds (kilograms) of pig manure are generated.

Photo 2. At present, most pig manure is discharged into the environment in an uncontrolled manner, often causing serious environmental damage.

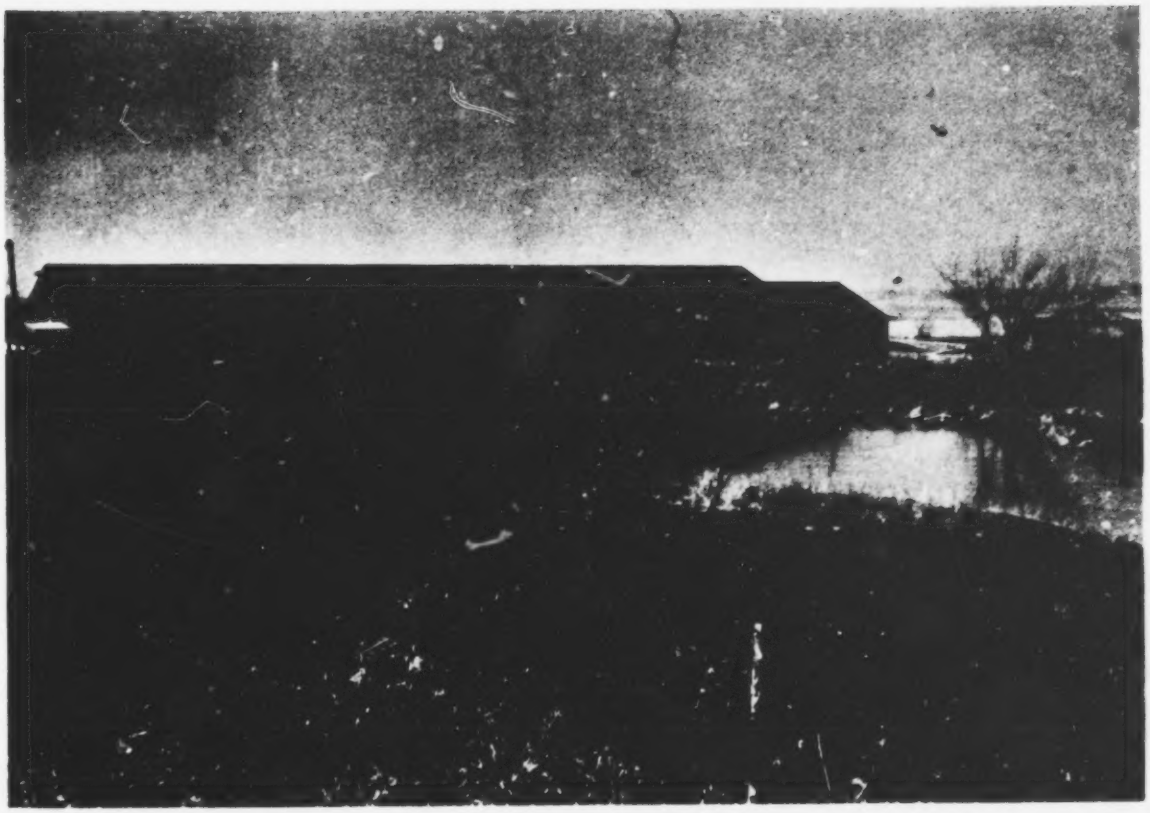

Photo 3. Schuster Farms, located at Gower, Missouri, recognized the problem and felt a responsibility to do something about it. This site--Schuster's Feeding Floor No. 7--was chosen as the location for a demonstration waste management system. The pond in the foreground supplies water to the feeding floor.

Photo 4. Feeding Floor No. 7, the demonstration site, consists of an old cattle barn converted to confined swine operations.

Photo 5. The facility consists of a concrete feeding floor of some 15,400 sq ft (1,430 m^2), fenced into four 70 ft x 55 ft (21 m x 17 m) pens, each equipped with self-feeders and automatic waterers.

Photo 6. Each of the four pens has a capacity of some 250 feeder pigs. Pigs are placed on the floor at about 30 lb (14 kg) and marketed when they reach around 200 lb (91 kg), after some 14 weeks.

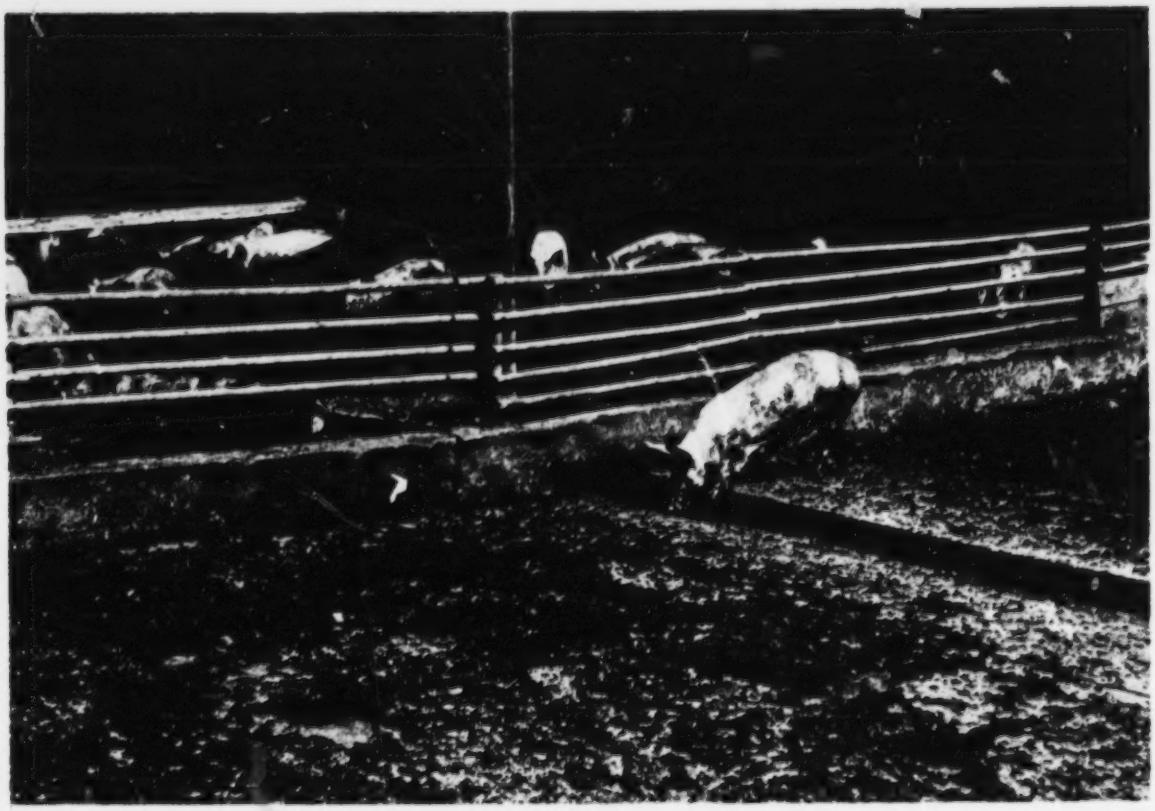

Photo 7. An 11 in. (28 cm) wide by 6 in. (15 cm) deep gutter runs the entire length of the floor, sloping down continuously from east to west (right to left).

Photo 8. The pens are normally scraped clean at least two or three times weekly during the summer and once weekly during the winter. The cleaning process employs one man operating a small front-end loader and another man on foot with a shovel, pushing the wastes into the gutter.

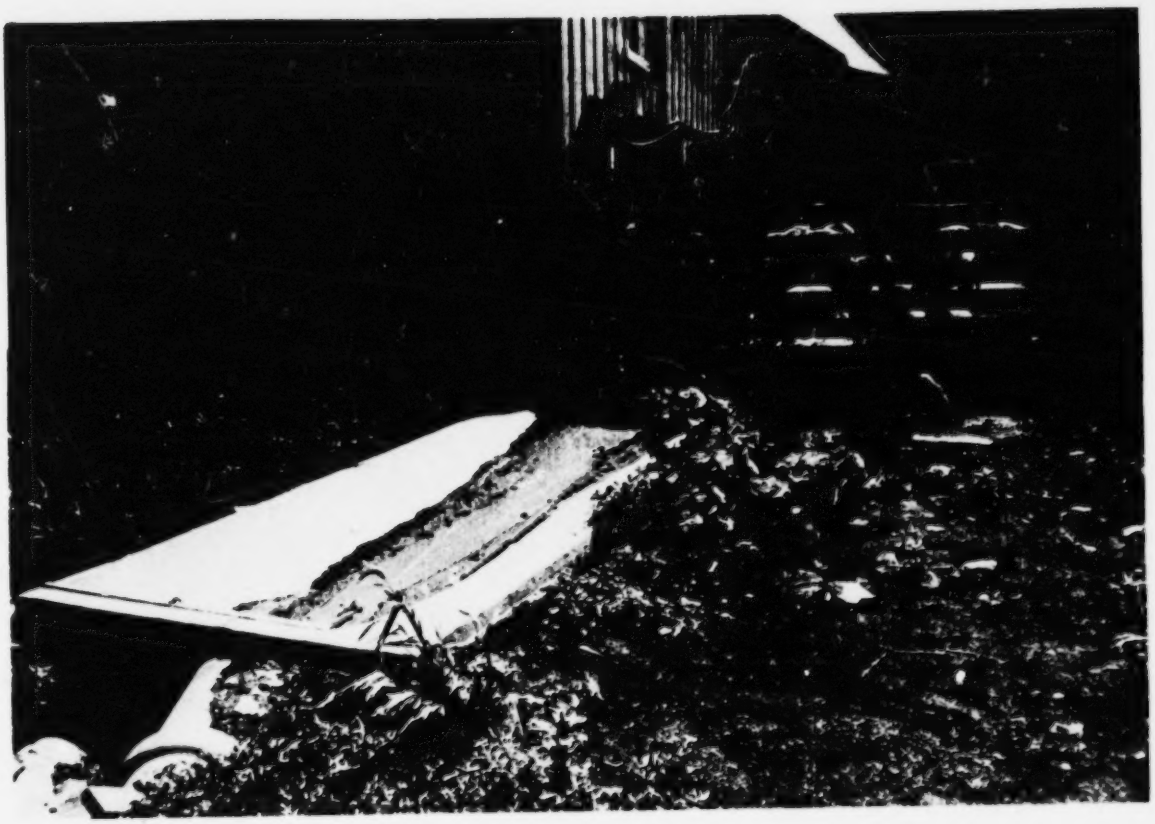

Photo 9. Water pumped from the pond into the gutter carries the wastes through the gutter to the west end of the feeding floor, where they flow into a small concrete collecting trough.

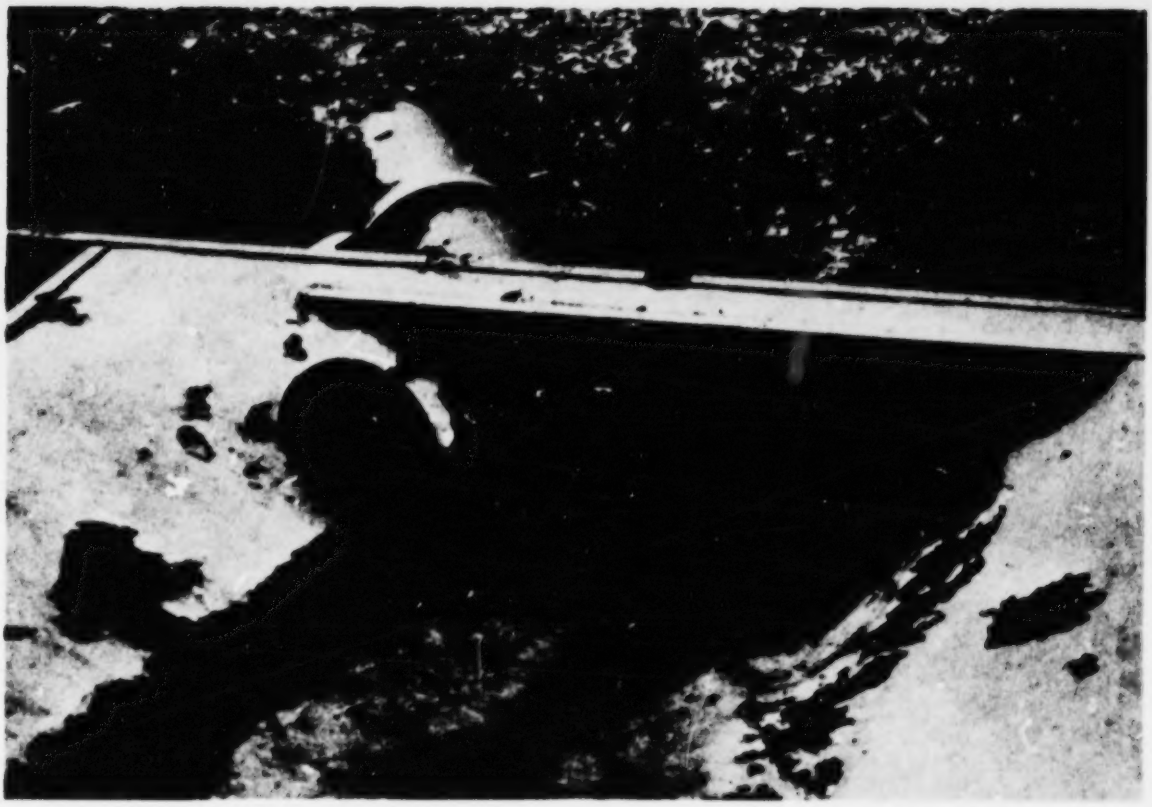

Photo 10. At the end of the trough, there are two routes that the wastes can follow. The drain on the bottom bypasses the aeration tank. By putting the plug over the bottom drain, wastes are directed into the aeration tank.

Photo 11. Here, the plug is in place and the wastes flow into the open end of the pipe.

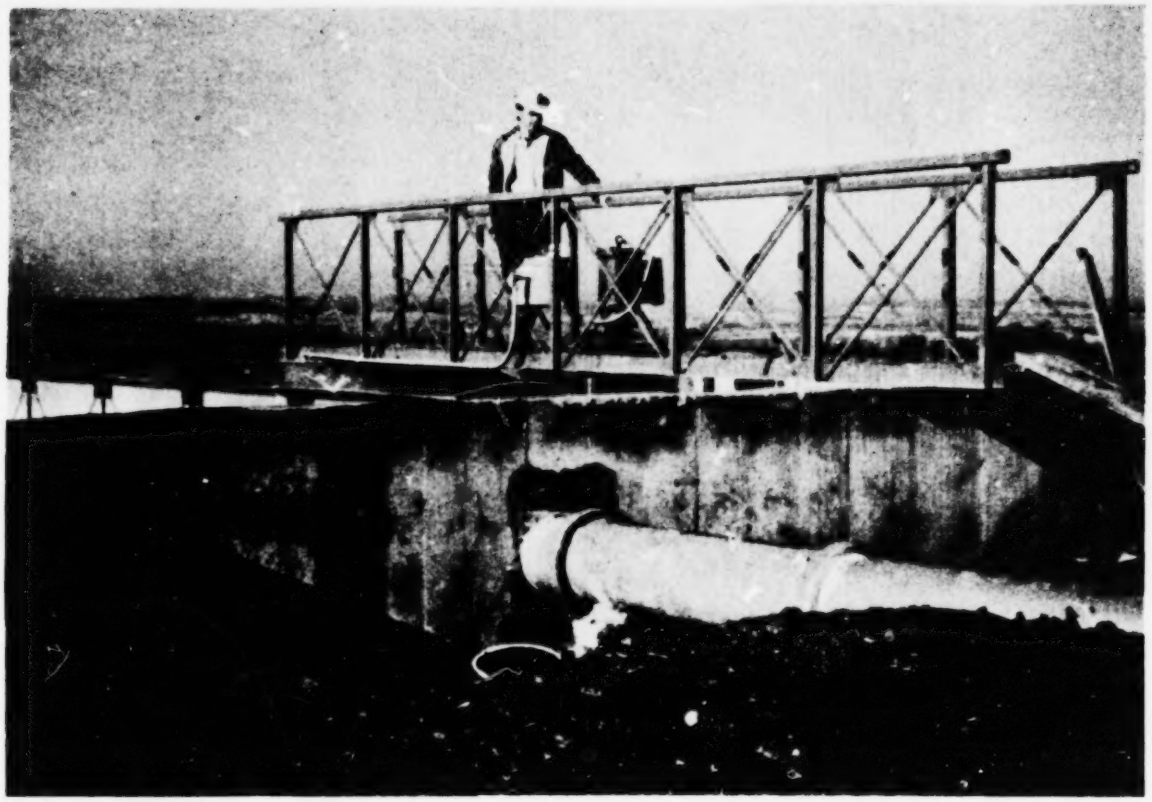

Photo 12. The wastes flow from the collecting trough through this pipe . . .

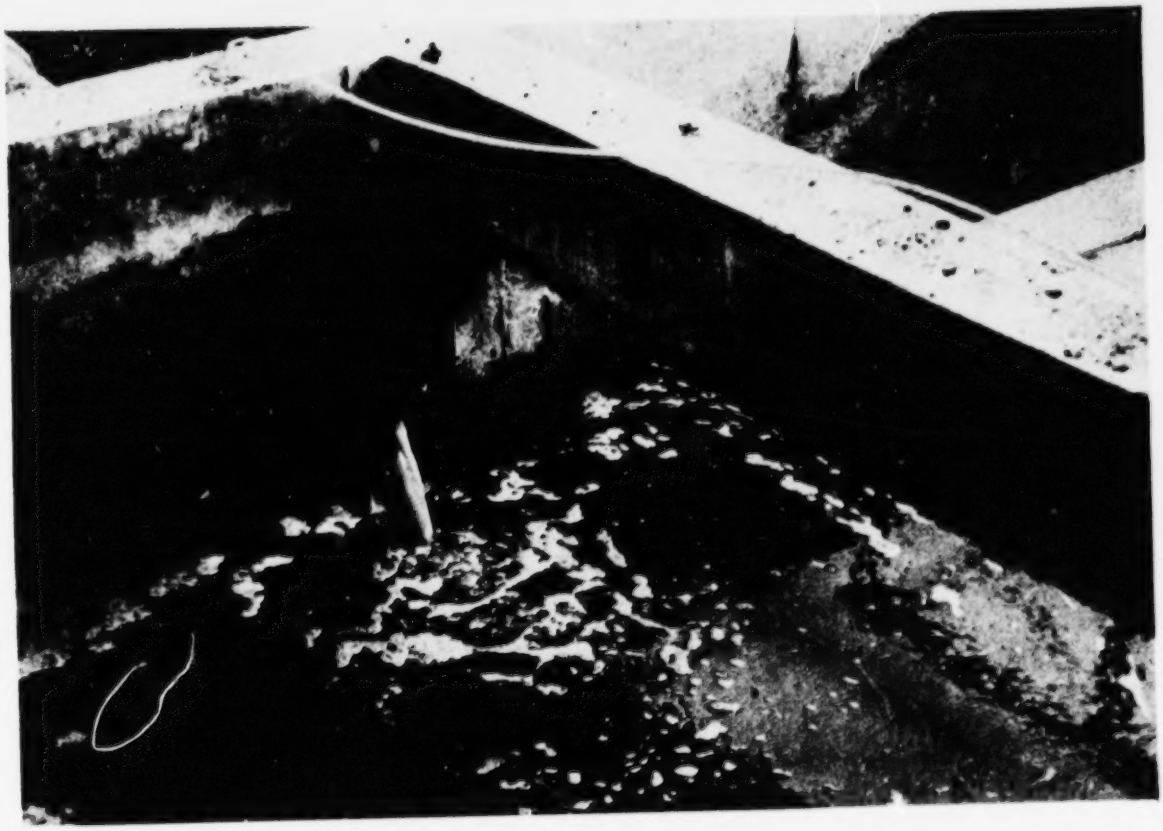

Photo 13. . . . and into the aeration tank.

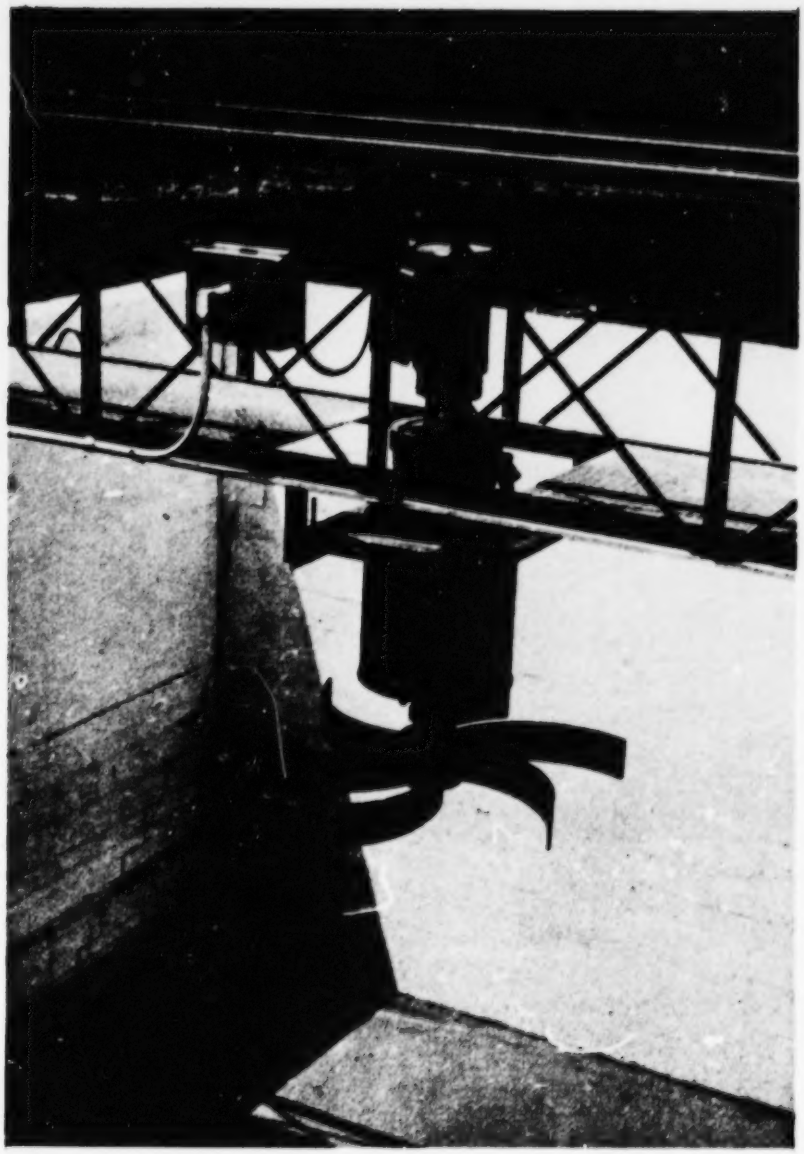

Photo 14. The 20 ft x 40 ft x 13 ft deep (6.1 m x 12.2 m x 4.0 m deep) reinforced concrete aeration tank is equipped with two of these 7.5 hp, bridge-mounted mechanical surface aerators. Only the aerator blades come in contact with the water.

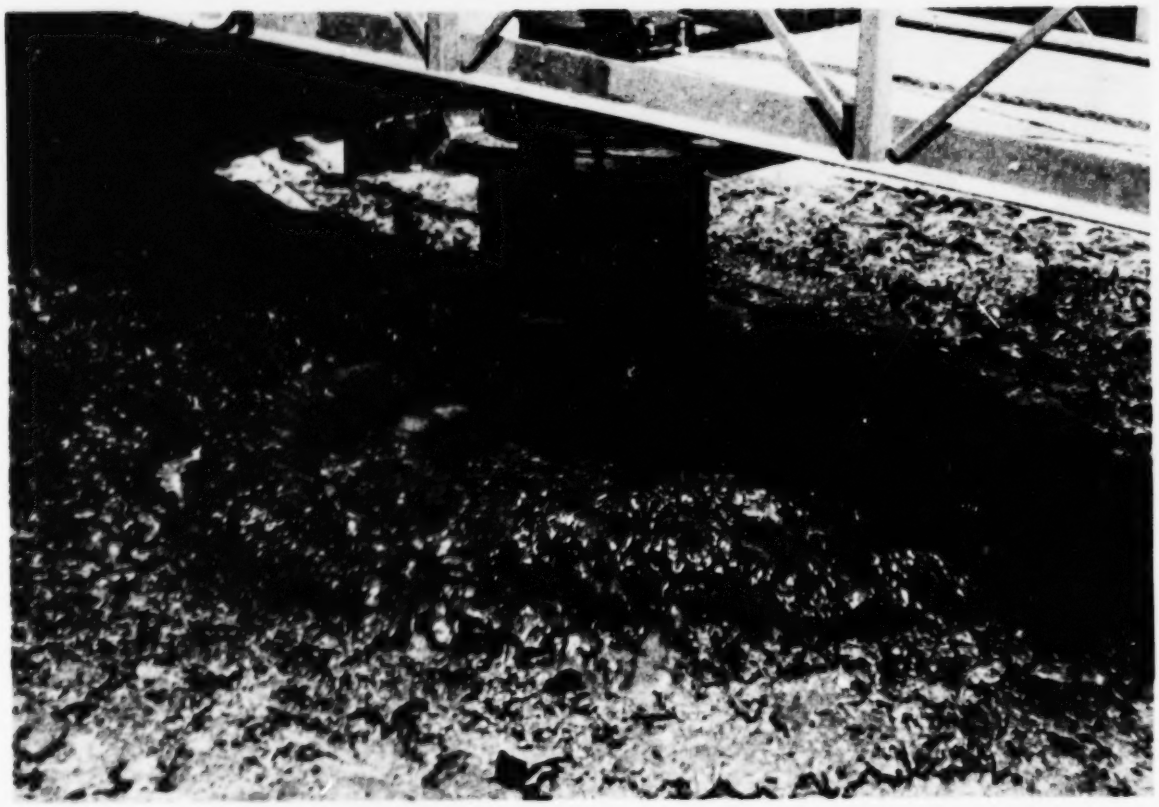

Photo 15. The rotating blades on the aerators throw the tank's contents into the air, thoroughly mixing incoming wastes with the mixed liquor already in the tank.

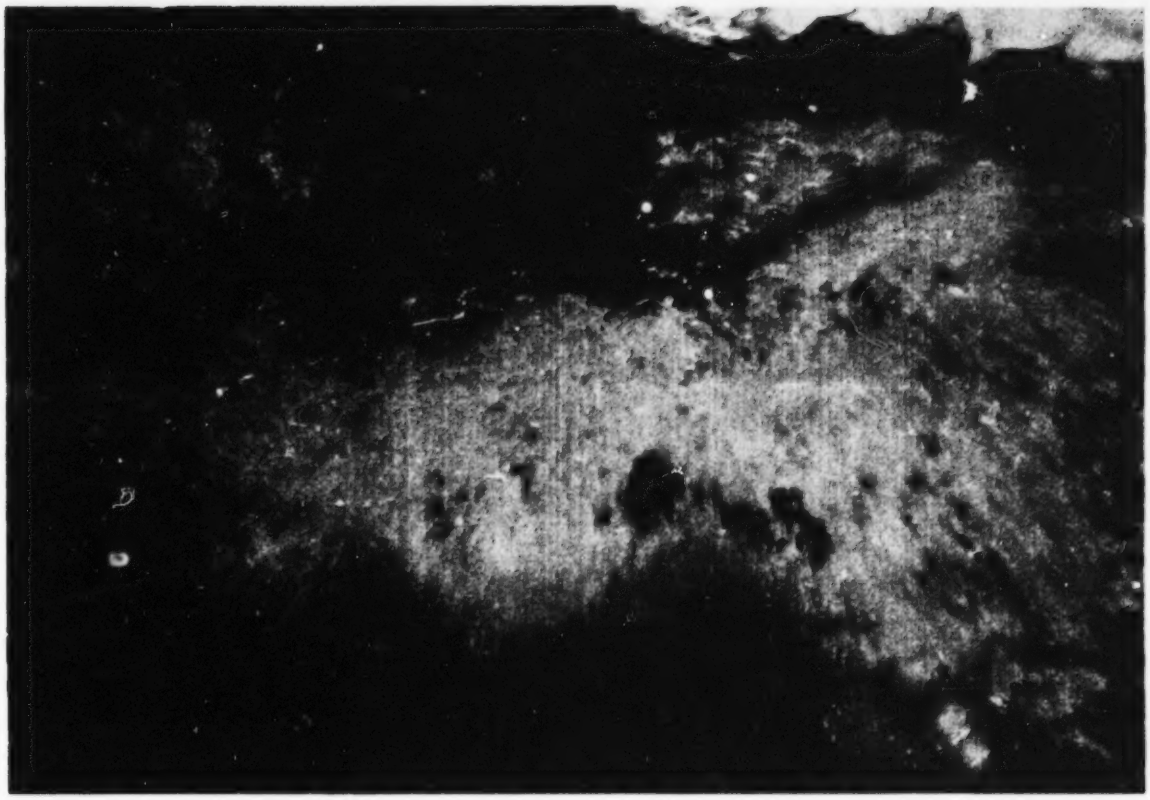

Photo 16. The wastewater thus thrown in the air absorbs oxygen from the air, necessary for the desired biological reactions to take place.

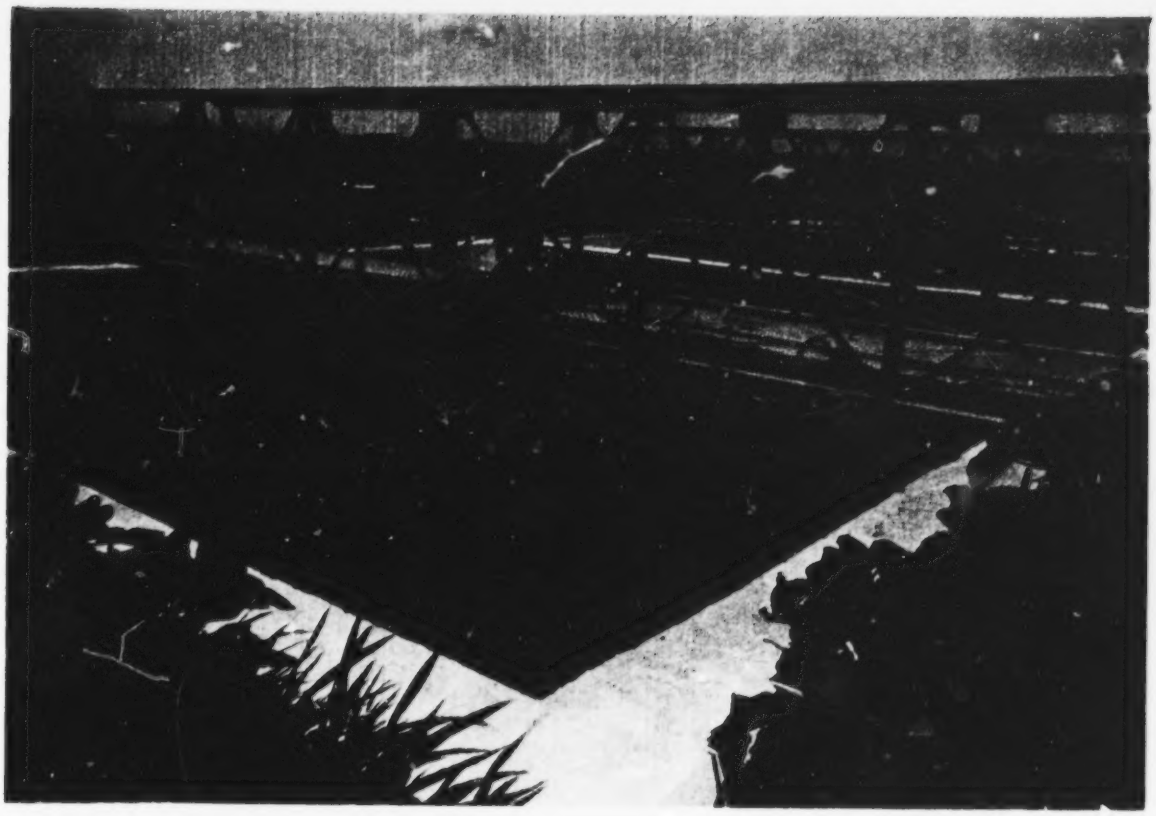

Photo 17. Each aerator is located at the center of a 20 ft x 20 ft (6.1 m x 6.1 m) section of the 20 ft x 40 ft (6.1 m x 12.2 m) tank, assuring good, continuous mixing characteristics thoughout the tank.

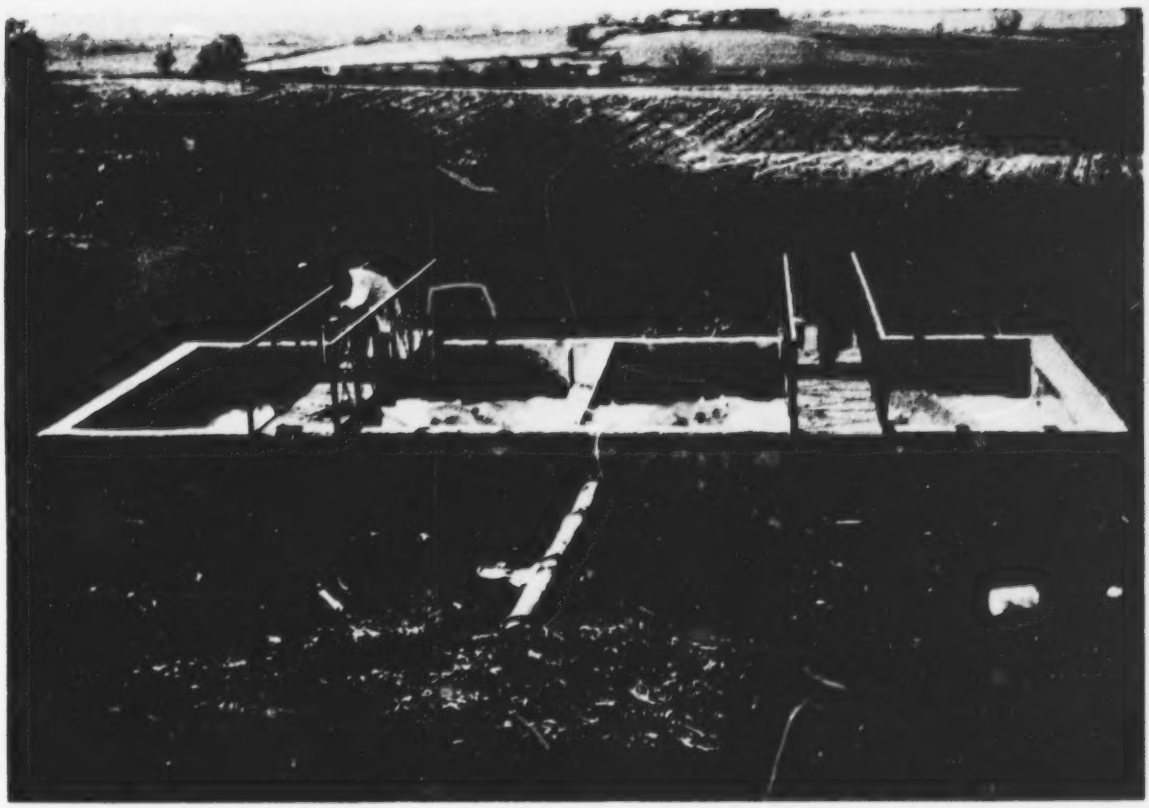

Photo 18. The aerators operate continuously, 24 hr/day, 365 days/year. Overall treatment efficiency falls generally in the 90% to 95% range. However, since no wastes whatsoever are discharged to the environment, treatment efficiency has only minor significance.

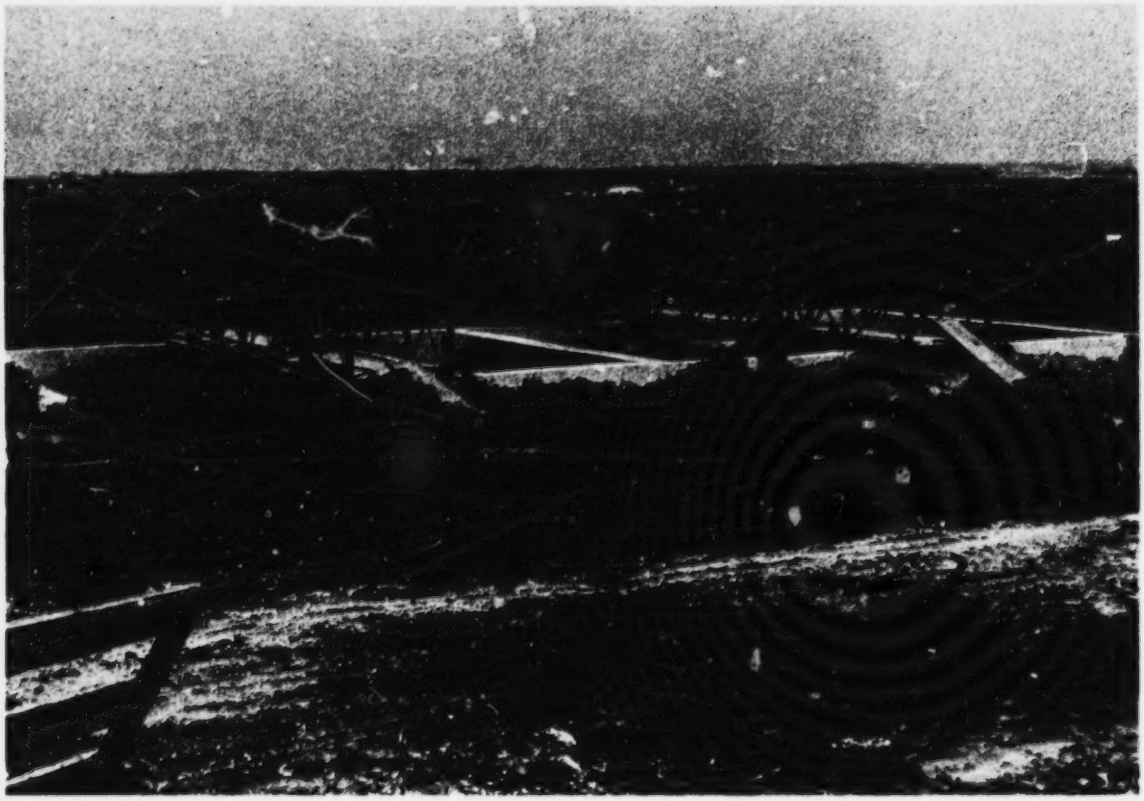

Photo 19. The waste treatment facility is relatively inconspicuous. It is free of odor and insects, and its electric motors operate quietly.

Photo 20. The liquid in the tank must be maintained at a constant level to achieve maximum aerator efficiency. The overflow pipe on the west side of the tank is set to maintain the optimum liquid level. As additional raw wastes are flushed into the tank, an equal quantity of treated wastes will flow out through the overflow to be retained in a settling pond for additional stabilization and ultimate disposal.

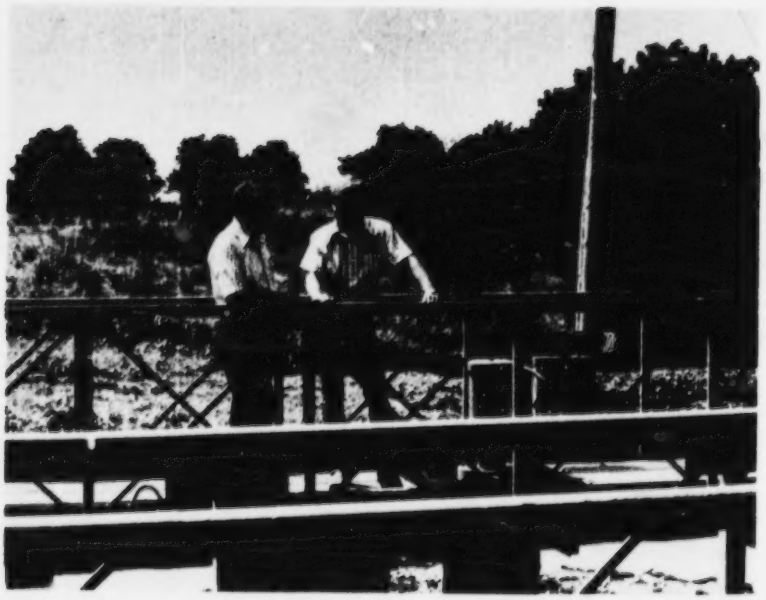

Photo 21. The system has now operated dependably for more than 2 years. It requires practically no maintenance, causes no nuisances, and need only be checked occasionally by farm personnel to make sure the liquid level in the tank is adequate. Here, the system designer Bill Park (left), and Schuster Farms' waste management specialist Gary Ellington (right), discuss the project, obviously unmolested by noise, odors or insects. The clean, quiet, odor-free operation is one of the system's most important features.

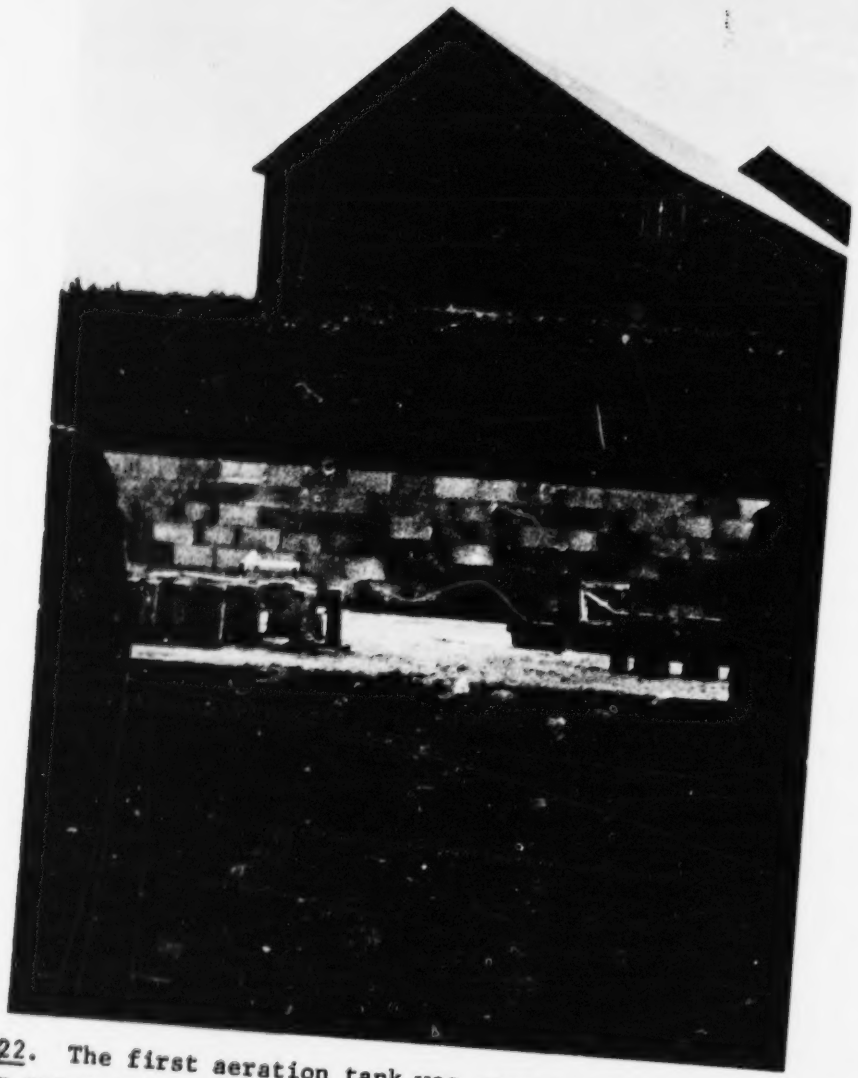

Photo 22. The first aeration tank was constructed of concrete block by farm personnel.

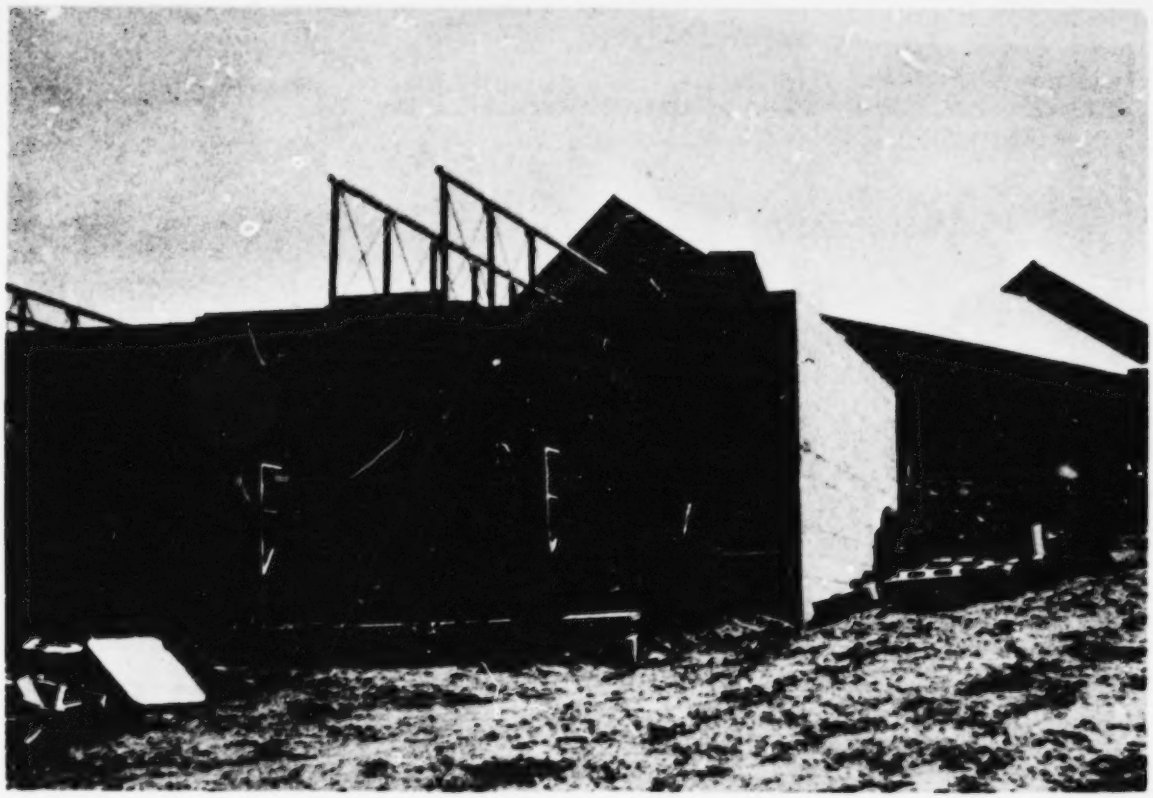

Photo 23. The concrete block tank was completed, the bridges were mounted on the tank, and the aerators were attached to the bridges. Then the process of filling the tank with water began.

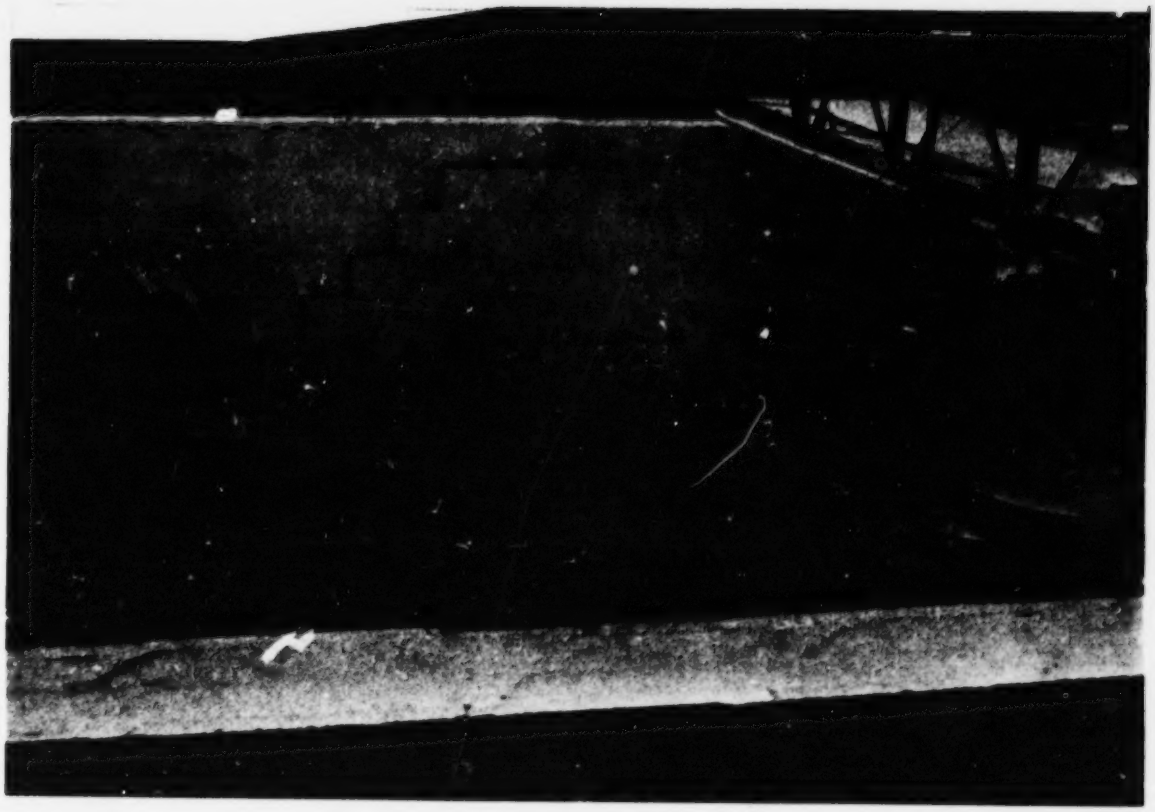

Photo 24. The tank filling process ended shortly after it began. With the water depth at about 4 ft (1.2 m), a lack of structural incegrity was noted in the west wall of the tank.

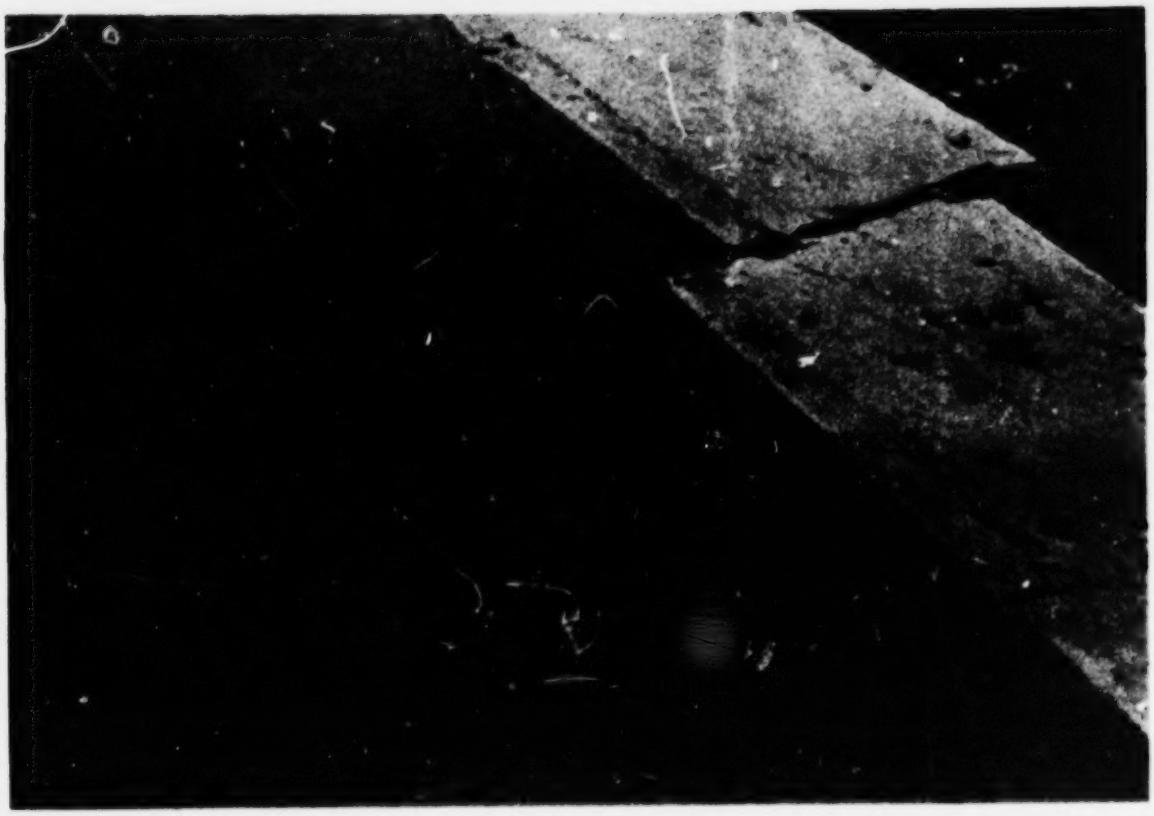

Photo 25. Fortunately, the large cracks that developed in the block wall permitted rapid evacuation of the tank's contents and thereby averted further disaster. Had the wall collapsed, the mechanical equipment would have crashed onto the concrete floor below, perhaps causing irreparable damage. As it was, however, the equipment was unaffected, remaining in place atop the fractured wall.

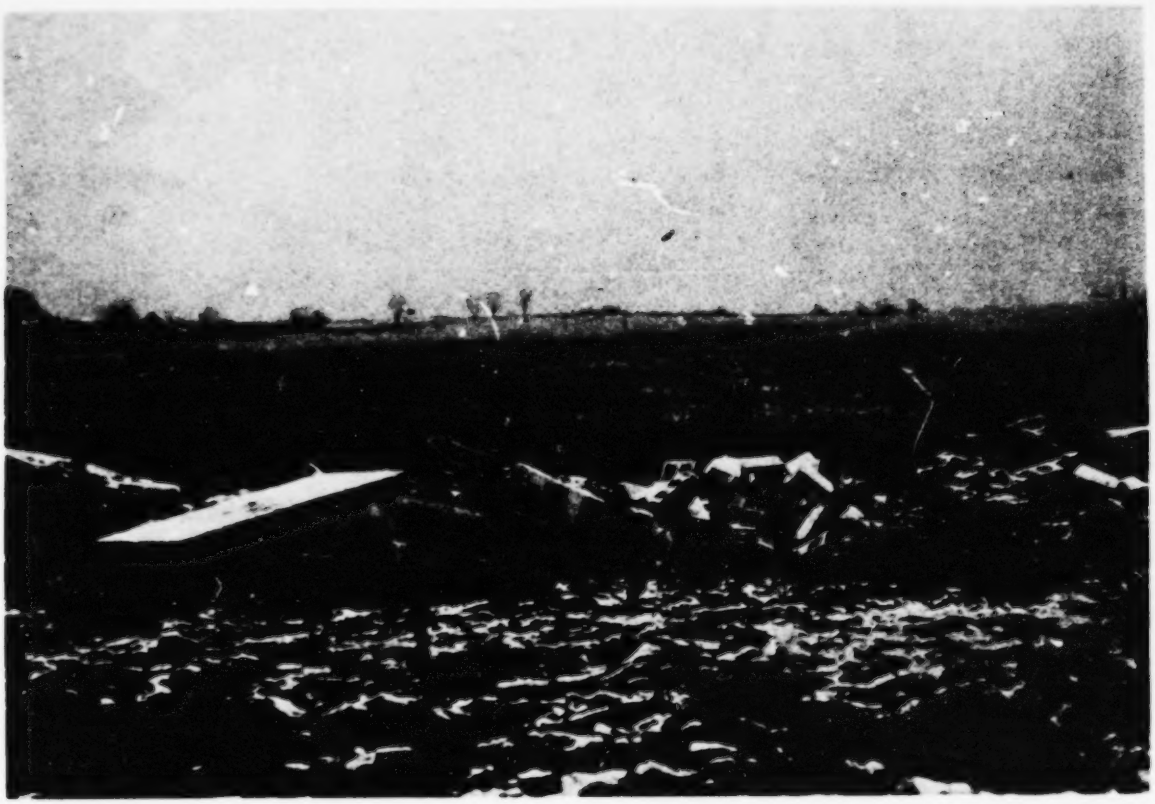

Photo 26. It was decided that, rather than attempt repairs on the concrete block walls, a new reinforced concrete tank would offer a better long-range solution. Consequently, the equipment was removed, the block walls were demolished, and the new tank was built by a contractor on the original foundation and floor slab.

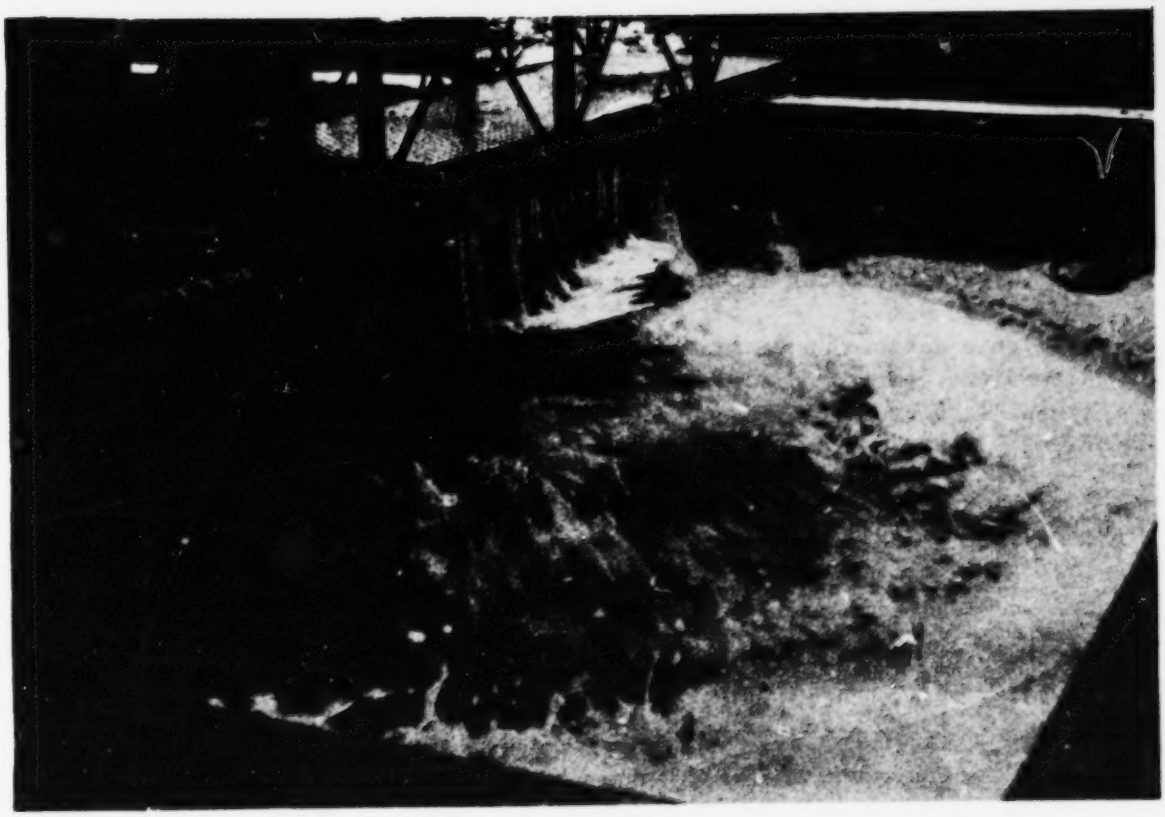

Photo 27. At first, a major area of concern was the possibility of freezing during winter operation. Freezing often adversely affects mechanical surface aeration systems. Here, however, the problems were minimal even during the coldest weather, with the equipment functioning normally throughout extended periods of extreme cold. Floating foam sometimes froze, blocking the overflow pipe, but the problem was quickly corrected.

SECTION IV

CHRONOLOGICAL HISTORY OF THE DEMONSTRATION PROJECT

JUNE 1970 THROUGH NOVEMBER 1970

Development of design criteria and parameters for the proposed waste treatment plant, to provide a basis for evaluation of aeration equipment, constituted the first major task in the demonstration project.

Available aeration equipment was carefully evaluated from manufacturers' literature and from discussions with manufacturers' technical representatives. Equipment that appeared to be capable of satisfying the specified design criteria received further evaluation from three standpoints:

1. Technical. The oxygen transfer capacity and fluid pumping characteristics of the equipment were of primary importance in evaluating the expected performance of the various types of equipment under operating conditions.

2. Economic. Since a major objective of this project was to demonstrate an economically feasible approach to waste treatment for the farmer, the expected cost of aeration equipment to farmers who might wish to use it in their own future operations was an important consideration.

3. Convenience. The ease of installation and maintenance, and the adaptability of the aeration equipment to a wide range of operating conditions, made up the third important consideration.

Based on these considerations, bids were obtained from manufacturers of the aeration equipment believed most suitable for the purposes of the demonstration project. After receiving the bids, recommendations were made regarding the specific equipment to be purchased.

The equipment ultimately selected for the project consisted of two 7.5 hp bridge-mounted, mechanical surface aerators, manufactured in Lenexa, Kansas, by the Smith & Loveless Division of Ecodyne Corporation.

The necessary reagents and equipment for performing the chemical and biochemical laboratory analyses to be used in monitoring the plant operation were also prepared at this time.

It was decided that established laboratory analysis routines would be adequate for making initial studies of the startup operations. Then laboratory studies of the analytical techniques that were made would permit modification of the routines to meet specific requirements of the sampling and analytical program best suited to the conditions of actual operation of the treatment unit.

At first the aeration tank was to be built of reinforced concrete, and located at the west end of the finishing floor. These original plans were, however, altered as follows:

1. The aeration tank would be located 50 ft (15 m) west of the end of the finishing floor, instead of adjacent to it. The purpose of this move was to allow additional flexibility in handling slug loads when the pens were cleaned. Should a sudden influx of organic material cause foaming or other problems, there would be sufficient room available to build a surge basin at the floor drain outflow. In this way, the waste flow to the aeration tank could be leveled out.

2. Instead of using reinforced concrete for the aeration tank walls, concrete blocks would be employed. This substitution was believed to be desirable for several reasons.

    a. Most farmers are accustomed to working with concrete block, which can be handled without special equipment and with a minimum of outside help.

    b. Concrete block is substantially cheaper than reinforced concrete for this size structure in a remote location.

    c. By eliminating the need for form work and reinforcing steel, construction could be greatly simplified and could proceed at the farmer's convenience.

3. In the original concept for this system, it was proposed that mixed liquor would be drawn from the aeration tank and pumped to the top (east) end of the finishing floor drain to provide for hydraulic carriage of manure down the drain and back into the tank. At Floor No. 7, the mixed liquor would have to be pumped some 200 ft (61 m) against a 25-ft (7.6-m) head, requiring considerable pumping capacity. To minimize pumping requirements and reduce costs, it was decided instead to draw flush water from a pond above and northeast of the pens.

Meanwhile, with construction under way, all necessary laboratory preparations were completed.

Tentative procedures for analyzing samples taken from the several processing stages in the operation of the waste treatment unit were developed. The procedures were adaptations of the "Standard Methods of Water and Wastewater" techniques which incorporate appropriate modifications for handling the types of samples to be available from the process units. These modifications included sampling techniques, methods for sample preservation and minor details of analytical procedures.

The nature of the operation and the distance to the Midwest Research Institute laboratory where analyses were to be made required that samples be preserved and transported in a manner that would retain sample integrity. A tentative sampling schedule was devised for securing, preserving, and transporting samples, and reagents and equipment for sampling the operations and conducting the analyses were stocked.

DECEMBER 1970 THROUGH MAY 1971

During the first part of this period, weather problems hampered construction of the aeration tank at Finishing Floor No. 7, while delivery problems delayed fabrication of the aeration equipment.

According to Dr. Ross E. McKinney, project consultant, the delays were probably beneficial. Dr. McKinney felt that biological treatment systems such as this should not start up during cold weather, since the necessary bacterial activity could not evolve.

By starting the system during March, the biological loading in the aeration tank should be built up to its normal operating level in late April. This should provide ideal conditions from an operating standpoint.

Smith & Loveless reported that the delay in equipment fabrication was caused by their gearbox supplier. Consequently, they changed gearboxes and obtained all necessary components. The bridges were completely fabricated, painted, and ready for delivery, and the aeration units were to be assembled and ready for shipment on March 8, 1971.

The waste treatment facility was actually completed in May. The aeration equipment was delivered, the steel bridges were mounted on the aeration tank, and the aerators were installed on the bridges. All electrical wiring was completed, the switchgear connected, and the mechanical equipment tested. A drainage system was devised to permit discharge of wastes directly from the finishing floor into the tank, with provision for bypass of wastes should problems arise. Oxygen transfer tests on

the completed system were scheduled for June 2, 1971. These initial tests were to be conducted by the Research Division of Clow Corporation.

The west wall of the aeration tank gave way on June 1. Fortunately, the large cracks which developed in the concrete block wall permitted rapid evacuation of the tank contents, thereby avoiding any more serious damage. The mechanical equipment was not damaged and remained mounted atop the tank, though with less than optimum structural stability.

This temporary setback will provide a valuable lesson to others who, in their own pollution abatement programs, might otherwise be tempted to merely duplicate the facility installed here. The mishap which occurred clearly demonstrated the importance of sound structural design, accompanied by good construction practices. While economy in construction is desirable, it should not be achieved by sacrificing structural integrity. This small-scale structural failure may well have averted some future large-scale structural disaster.

Consequently, in order to minimize the possibility of similar problems occurring in the future, specific tank design and construction details were developed, clearly delineating all dimensions, construction materials and reinforcing details.

To restore the damaged treatment facility to an operable condition would have entailed the following steps:

1. Remove bridges, mechanical and electrical equipment and appurtenances.

2. Remove the damaged portions of the tank walls.

3. Thoroughly flush the tank, and divert the waste stream around the tank.

4. Drill holes in the floor slab so that a new wall could be firmly anchored.

5. Pour additional concrete footings for supporting pilasters.

6. Replace walls and construct pilasters with reinforced block, providing for firm bonds between floor slab, pilaster footings, pilasters, and walls.

7. Install vertical reinforcing in block holes.

8. Pour a 4-in. (10-cm) reinforced concrete cap, tied to the block wall and allowing for a strong structural connection between the tank and the steel bridges.

9. Reinstall the bridges, electrical and mechanical equipment.

Because, at best, the above procedure would have resulted in a patched-up tank certain to cause considerable mental anxiety among designers, builders, operators and observers, it was decided to completely scrap the block walls and arrange with a contractor for construction of a reinforced concrete tank, as originally envisioned.

JUNE 1971 THROUGH NOVEMBER 1971

The first half of this period could best be regarded as a period for reconstruction, consolidation and reflection on the valuable insights gained during the preceding period.

Probably the most important points demonstrated thus far in connection with the project concerned the many and diverse problems that a typical livestock producer might be expected to encounter in constructing a waste treatment facility. To briefly review just a few of the delay-causing highlights:

1. Rock was encountered during excavation for the aeration tank, which necessitated some revision in the original plans. This could pose a serious problem for many farmers in constructing below-grade facilities of this type.

2. Concrete block was substituted for the originally planned reinforced concrete walls, to reduce costs and to permit the work to be performed by farm personnel. While a reinforced concrete tank may be somewhat "overdesigned" in terms of the anticipated structural loadings, an ordinary basement foundation-type concrete block structure might be considered equally "underdesigned" in terms of its structural stability.

3. Delays in the fabrication and delivery of aeration equipment were experienced. This, of course, could be expected in almost any type of project.

4. The tank broke as it was being filled, strikingly emphasizing the importance of sound structural design and good construction techniques. Thus, between the original design

and the actual construction, the problem was "bracketed," with both overdesigned and underdesigned structures identified. The reconstructed tank represents a near optimum point between these two extremes.

In summary, a number of important points were clearly demonstrated that must be considered in the planning and construction of a livestock waste treatment facility. While there was admittedly some disappointment felt in having encountered so many problems, it was far better to have experienced them in connection with a pioneering demonstration project where the results can greatly benefit those who follow.

Finally, the reconstructed waste treatment facility became fully operable and evaluation of the system's operating characteristics and equipment performance commenced.

Preliminary oxygen transfer tests were conducted on November 17 with Smith & Loveless research personnel familiar with the equipment. Some minor problems were encountered in the tests and the results were inconclusive, though impressive.

Some dilute swine wastes were present in the aeration tank, washed in by rain during the preceding week. The oxygen uptake rate in the tank, as determined by Smith & Loveless in their laboratory, was 102 mg/liter/hr.

The aerators raised the dissolved oxygen (DO) level in the mixed liquor from 0.5 part per million (ppm) to 5.5 ppm in 8 min, an average net gain of 0.6 ppm/min or 37.5 ppm/hr. During this time, the motors were each drawing 6.5 actual horsepower.

Simply adding the oxygen uptake rate in the waste (102 mg/liter/hr) to the net oxygen transfer rate (37.5 ppm/hr) gave a gross transfer rate of 139.5 mg/liter/hr in the dilute waste. For the 50,000-gal. (189,250-liter) tank, this represented a total oxygen transfer of approximately 59 lb/hr (27 kg/hr), or 4.5 lb (2 kg)/hp-hr. Since the equipment was rated by its manufacturer at only 4.0 lb (1.8 kg)/hp-hr in tap water, these results were not at all disappointing, however crude crude the methods by which they were obtained.

Flushing of swine wastes into the tank was scheduled to begin in mid-December. Although cold weather is admittedly a poor time to begin operation of a biological treatment system, this schedule would facilitate a gradual buildup of organic material in the tank and allow observation of the mechanical performance of the system throughout the winter season.

DECEMBER 1971 THROUGH MAY 1972

Cold weather set in before the treatment system's operating characteristics could be fully evaluated. Clow Corporation research personnel attempted some oxygen transfer tests on December 1 and 2, but below-freezing temperatures prevented their obtaining any useful results.

While biological activity in the waste treatment system was essentially nil during cold weather, the mechanical performance of the system was outstanding. It is difficult to visualize any worse weather conditions than those that were encountered during the winter of 1971-1972. Temperatures at the demonstration site reached 17 degrees below zero, and bel w-zero temperatures prevailed over an entire week. Nevertheless, the equipment continued to operate and the tank contents did not freeze.

Only a few minor problems were encountered during the first 3 months of operation, most of them related to the weather and none of them serious.

Considerable foaming occurred as the tank was filling with wastes. This is to be expected during the startup of any mechanically aerated biological waste treatment system and corrects itself as warmer weather permits the bacterial action necessary to metabolize the organic materials in the waste.

A second problem was brought about by the sudden cold weather, which quickly froze the foam that was floating on top of the water in the tank. The frozen foam then plugged the overflow drain. Then, as additional liquids flowed into the tank, the aerator motors became overloaded and were shut off by the circuit breakers. The situation was temporarily rectified by pumping some liquid out of the tank, dropping the level to where the aerators could function normally. A variable-level discharge device could provide a permanent solution to this problem.

Everything considered, the system operated quite successfully over an extremely difficult period. Sampling and laboratory analysis began as soon as the weather permitted.

Initial oxygen transfer tests on the aeration equipment indicated an oxygen transfer rate of approximately 3 lb (1.36 kg)/hp-hr in the waste. The addition of a 2-day accumulation of wastes to the tank over a 1-hr period lowered the dissolved oxygen level in the mixed liquor from 9.4 mg/liter to 6.3 mg/liter. Thus, it appeared that the system would accommodate considerably heavier loadings than it was currently experiencing.

The sampling and laboratory analysis program was initiated on April 27. Samples were taken prior to, during, and after pen cleaning, as follows:

1. Raw waste samples were scraped from the feeding floor at 10 random locations. The sample included whatever was on the floor and could be expected to end up in the aeration tank--manure, spilled food, straw, dirt, etc.

2. A sample of the mixed liquor in the aeration tank was drawn from near the center of the tank at about a 5-ft (1.5-m) depth.

3. While the pen was being cleaned, samples were drawn from the wastes flowing into the tank. These samples were taken at 1-min intervals during the time that cleaning was under way. When cleaning was completed, a sample was taken from the composite mixture.

4. After the waste inflow to the tank stopped, another sample of the mixed liquor in the aeration tank was taken at the same location as before (in Sample 2).

All samples were then placed in an ice chest and brought directly to MRI for laboratory analysis.

The laboratory tests encompassed both the manure characteristics and the treatment system's operating characteristics. The following tests were performed:

1. Manure Characteristics (Sample 1)

   a. Moisture content

   b. Ash

   c. Manure strength

      (1) BOD

      (2) COD

      (3) Organic nitrogen

      (4) Ammonia nitrogen

2. Treatment Efficiency (Samples 2, 3 and 4)

   a. BOD

b. COD

c. Suspended solids

d. Volatile suspended solids

e. Soluble solids

f. Volatile soluble solids

g. Organic nitrogen

h. Ammonia nitrogen

i. Nitrite nitrogen

j. Nitrate nitrogen

The early tests, while inconclusive, did indicate that the system was functioning satisfactorily, with some 96% of the BOD removed in the aeration tank.

JUNE 1972 THROUGH NOVEMBER 1972

Sampling and laboratory analysis continued on a weekly basis throughout the first 3 months of this period, with interesting results.

The 14-week sampling period was divided into three parts, covering the first four, middle six, and last four weeks. This allowed comparison of waste characteristics and treatment plant performance between the different periods as the hogs increased in size from a 50 lb (23 kg) average during the first period, to 100 lb (45 kg) during the second, and 175 lb (79 kg) during the final period. Average hog weight over the 14-week period was approximately 110 lb (50 kg).

Waste samples, scraped from random locations on the feeding floor, ranged from fresh to 3 days old and included manure, spilled feed, dirt, straw, and whatever else might be on the floor. The average 5-day BOD of these raw wastes was 152,500 mg/liter, substantially higher than values reported in the literature.

These raw wastes, diluted with pond water used for flushing, made up the influent to the aeration tank. From 1,500 to 2,700 gal. (5,700 liters to 10,200 liters) of water were used for flushing the wastes through the gutter, the amount depending on how long the floor-scraping process took.

The raw waste's 152,500 mg/liter average BOD was diluted to 46,440 mg/liter by the time it entered the treatment tank. The average effluent--actually an average of the mixed liquor in the tank before and after the floor cleaning operation--was 1,680 mg/liter, representing a reduction of 96.4%.

Similarly, over the 14-week period, COD was reduced by 91.7%; suspended solids by 89.3%; and total nitrogen by 89.6%.

All sampling techniques and laboratory analyses were conducted in accordance with Standard Methods, and the week-to-week results were remarkably consistent throughout the test period.

Additional experimentation was planned for the following period, employing a new type of aerator. A single, 7.5 hp, floating aerator (manufactured by Roycraft Industries, Kansas City, Missouri), was supplied and installed totally at the manufacturer's expense for evaluation. It was believed that 7.5 hp would provide sufficient mixing and oxygen transfer for these wastes; the system would thus benefit in several ways:

1. Energy costs would be cut in half.

2. The capital tied up in equipment would be approximately half.

3. The floating unit would maintain optimum performance regardless of the level of liquids in the aeration tank.

In terms of system economics, then, it was hoped that this new approach would constitute a major breakthrough. Instead of the $1.00/hog, 1/2 cent/lb (1.1 cent/kg) of pork cost estimated for the original system, costs could drop perhaps to the $0.60 to $0.70/hog, 1/3 cent/lb ($0.73/kg) level. This, of course, would make it far more desirable from the farmer's standpoint.

The original system was nevertheless considered an outstanding success as a demonstration project, both technically and in terms of the amount of favorable publicity it received in newspapers and farm magazines.

The two bridge-mounted aerators were moved to the ends of the aeration tank and disconnected, and the single floating unit moored in place at the center of the tank.

The new installation functioned smoothly for some time without major incident, proving generally satisfactory in performance and dependable in operation. Several shutdowns occurred, all of which were handled

promptly by the manufacturer, Roycraft Industries, Inc., of Kansas City, Missouri. Most of the mechanical difficulties experienced could be considered normal "startup" type malfunctions, for which the necessary modifications were made.

Sampling was discontinued with the advent of cold weather when little biological activity was taking place, pen scraping was irregular, and fewer pigs were on the feeding floor.

Several observations were worth noting on the overall system performance. Mechanically, both the bridge-mounted and the floating aerators performed dependably and continuously even during the coldest weather, with ambient air temperatures remaining well below freezing for prolonged periods, and frequently droping below 0° F (-18° C). The tank contents did not freeze.

The floating unit was far less sensitive to variations in the liquid level in the aeration tank than the fixed, bridge-mounted equipment. However, the floating aerator was anchored to the tank sides with cables, and when the liquid level dropped more than about 2 ft (0.6 m), the aerator was suspended in the air by its cables, hanging above the water. This could cause considerable damage to the motor.

In contrast, however, the bridge-mounted aerator allows a maximum variation in liquid level of only a few inches; even a 1 in. (2.5 cm) fluctuation affects treatment efficiency by as much as 17%.

It appeared, therefore, that in an operation where equipment care and maintenance must be kept to an absolute minimum, the floating aerator might be preferable to the fixed unit, especially when there is no continuous inflow to the aeration tank. The remaining question dealt with the relative treatment efficiency of the two types of aerators.

DECEMBER 1972 THROUGH MAY 1973

The treatment system continued to function well during late 1972 and early 1973, with several short shutdowns occurring; these, however, were handled by the equipment manufacturer without incident. They switched to a different and reportedly more dependable motor and experimented with different components in order to find the combination best suited to this operation.

During late fall and winter when pen cleaning operations were conducted less frequently than in the summer, the liquid level in the aeration tank tended to drop substantially, necessitating the addition of water to keep it at a satisfactory level. Thus, the treatment facility was

found to be not only zero-discharge, but negative-discharge; fresh water had to be added just to keep the mixed liquor at a constant volume. There was, of course, no discharge of any kind reaching any rivers or streams at any time. Tank overflows, when they occurred, were retained in the settling pond.

There were no complaints of objectionable odors from the treatment system.

In all, the treatment facility continued to demonstrate that environmental protection could be compatible with existing confined livestock feeding operations.

The floating "Aerolator" was in service throughout this 6-month period.

Sampling of waste influents and effluents during the time that the equipment was functioning properly indicated highly satisfactory performance and treatment efficiency, with from 90%-95% of the pollutants removed in the aeration process.

However, some serious mechanical problems developed in early spring which eventually led to abandonment of the floating aeration unit.

Blocks of wood (2 in. x 4 in. (5 cm x 10 cm)) frequently found their way into the aeration tank and were drawn into the aerator, causing severe damage on several occasions. The source of these boards was never found, nor was the means by which they gained entry to the tank. Possibly, the boards were dislodged from the fence by the pigs and subsequently washed down the gutter and into the tank. Or, they could have been thrown or dropped in the tank.

Nevertheless, the problem recurred frequently enough to be quite troublesome, both for the operator and the manufacturer. While the equipment was shut down, solids would build up in the tank and objectionable odors would develop. Consequently, it was decided to return the two Smith & Loveless bridge-mounted aerators to service.

Still there was no doubt that the floating aerators could do an adequate, dependable job, especially if they were incorporated during the design phase of a project. The tank configuration at the demonstration site was specifically designed for the bridge-mounted units, and the problems associated with the floating aerator should in no way be considered a reflection on the equipment.

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With the original Smith & Loveless aerators back in service, the waste treatment system has operated continuously, dependably and efficiently. The results can be considered nothing less than 100% effective.

The small quantity of wastewater flowing from the aeration tank to the settling pond dries into a granular substance that has absolutely no odor. Surprisingly, there are no flies around the entire tank area. The system has effectively eliminated all air, water and solid waste problems commonly associated with confined hog raising.

In summary, the demonstration project has proven remarkably successful from a technical standpoint. And economically, the system appears to offer at least a reasonable solution to what could otherwise become an expensive problem.

SECTION V

SYSTEM DESIGN

PHYSICAL DESIGN

The waste treatment plant design was based on a hog population of 1,000, ranging in size from 30 lb to 225 lb (14 kg to 102 kg) and averaging 100 lb (45 kg) each. Waste flow, consisting of urine, manure, spilled food and water, was estimated at 1,500 gal. (5,700 liters) daily. The 5-day biological oxygen demand (BOD) of the raw waste was expected to be around 33,000 mg/liter.

By way of comparison, the hydraulic waste loading would be comparable to that generated by only 15 people, while the organic loads on the treatment facility would exceed those produced by more than 2,400 people. The raw wastes going into this treatment plant are more than 100 times as concentrated as the inflow to most municipal treatment plants.

In terms of treatment efficiency, the equivalent of conventional secondary treatment was desired. For a completely mixed aerated lagoon, treatment efficiency is related to detention time, and to achieve the desired 95% BOD removal attainable in a well designed municipal treatment plant requires that wastes be held in the aeration tank for some 30 days.

The detention time and daily waste flow, then, set the minimum tank size at 1,500 gal. (5,700 liters)/day x 30 days = 45,000 gal. (171,000 liters). It was decided to use a 50,000-gal. tank.

To obtain good mixing and fluid flow in this type of system, the tank should be set up in square or round modules, each with a depth of about half its length or diameter. Square, rectangular and circular configurations were examined.

The dimensions required in these various shapes were found to be approximately as follows:

Square: 24 ft x 24 ft x 12 ft deep (7.3 m x 7.3 m x 3.7 m deep)

Round: 26 ft diameter x 13 ft deep (8 m diameter x 4 m deep)

Rectangular (two square modules): 19 ft x 38 ft x 9.5 ft deep
(5.8 m x 11.6 m x 2.9 m deep)

These three designs should perform equally well. However, it was felt that the depth should not exceed 10 ft (3 m) for several reasons, the most important one being that a thick layer of rock was encountered at about that depth. Also, the smaller module offers better adaptability to a wide range of operating conditions, and permits the use of smaller aeration equipment. Each 19 ft x 19 ft x 9.5 ft (5.7 m x 5.7 m x 2.9 m) module can accommodate the wastes from 500 hogs, and any size hog raising operation can be handled by adding modules.

In this case, the aeration tank dimensions were finally set at 18 ft x 38 ft x 13 ft deep (5.5 m x 11.6 m x 4 m) (allowing for a 10 ft (3 m) liquid depth plus 3 ft (1 m) of freeboard); outside, the tank measures a convenient 20 ft x 40 ft x 13 ft (6.1 m x 12.2 m x 4 m).

For reasons noted earlier in this report, reinforced concrete construction is strongly recommended for the aeration tank. Dimensions and reinforcing details are included in the Appendix.

BIOLOGICAL DESIGN

In order for the desired biological reactions to take place in the aeration tank, the system design must provide for the transfer of adequate quantities of oxygen from the atmosphere to the wastewater.

This oxygen transfer requirement, in turn, imposes certain mechanical requirements on the pumping capacity of the aeration equipment.

The raw waste, with a 5-day BOD of 33,000 mg/liter and an average oxygen uptake rate of 43 mg/liter/hr, required the transfer of 21.5 lb (9.8 kg) of oxygen per hour at 20° C. Alpha, the ratio of oxygen transfer efficiency in the waste to that in pure water, was estimated at 0.8; beta, the ratio of the oxygen concentration in the waste when fully saturated to that in tap water, was estimated at 0.7. The ambient oxygen concentration in the mixed liquor was set at 2.0 mg/liter. The general design parameters for the proposed swine waste treatment plant are summarized in Table 1.

Given these parameters, the oxygen concentration of the wastewater at saturation is found to be 6.23 mg/liter.

The oxygen transfer rate in wastewater (R_w, in pounds of oxygen per horsepower-hour) could then be calculated from the following equation:

$$R_w = \alpha R_s \left(\frac{C_{sw} - C_e}{C_{st}}\right) (1.024)^{t-20} \qquad (1)$$

Table 1. GENERAL DESIGN PARAMETERS FOR PROPOSED SWINE WASTE TREATMENT PLANT AT SCHUSTER FARMS, GOWER, MISSOURI

Average population	1,000 hogs
Average hog weight	100 lb (45 kg)
Average waste flow	1,500 gpd (5,700 liters/day)
Raw waste BOD_5	33,000 mg/liter
Aeration tank size	20 ft x 40 ft x 10 ft (6.1 m x 12.2 m x 3.1 m)
Average oxygen transfer requirement	21.5 lb/hr (9.8 kg/hr)
Average oxygen uptake rate	43 mg/liter/hr
Design temperature	20° C
Alpha	0.8
Beta	0.7
Oxygen concentration at saturation (tap water)	8.9 mg/liter
Ambient oxygen concentration in mixed liquor	2.0 mg/liter
Tank turnover time (K_{La})	12.7/hr
Required pumping rate	762,000 gal/hr (2,880,000 liters/hr)

where

R_a = the oxygen transfer rate in tap water
C_{sw} = the oxygen concentration of the wastewater at saturation
C_e = the ambient oxygen concentration in the mixed liquor
C_{st} = the oxygen concentration of saturated tap water
t = the ambient temperature

This equation yields the following results:

$$R_w = (0.8)\ (4.0)\left(\frac{6.23 - 2.0}{8.9}\right) \times (1.0) = 1.52 \text{ lb/hp-hr}$$

$$= (0.8)\ (1.816)\left(\frac{6.23 - 2.0}{8.9}\right) \times (1.0) = 0.69 \text{ kg/hp-hr}$$

and the required horsepower is found to be:

$$\frac{21.5}{1.52} = 14.2 \text{ hp}\left(\frac{9.8}{0.69} = 14.2 \text{ hp}\right)$$

so two 7.5 hp mechanical aerators were recommended.

Based on these design parameters, it was determined that the aeration equipment, in addition to transferring 21.5 lb (9.8 kg) of oxygen per hour, should be capable of pumping at least 635,000 gal/hr (2,400 m^3/hr) of the liquid, thus "turning over" the aeration tank's contents at a rate of 12.7 times per hour, or once every 4.7 min.

EQUIPMENT SELECTION

For mechanical surface aerators rated at 4.0 lb (1.82 kg) of oxygen transfer per horsepower-hour in tap water (as most are), actual oxygen transfer in the mixed wastes under design conditions will be far less. Here, only about 1.5 lb (0.68 kg) of oxygen transfer per horsepower-hour is expected, thereby requiring some 15 hp of installed aeration capacity. Since the system is set up in two modules, two 7.5 hp units were specified.

Only two mechanical surface aerators were available at the time that appeared capable of satisfying both the oxygen transfer and fluid pumping requirements of the proposed system. One was made by Clow Corporation, the other by Smith & Loveless. Both claimed oxygen transfer of 4 lb (1.82 kg)/hp-hr in tap water at 20° C; both were rated at well over the required pumping rate--the 7.5 hp Clow unit at 5,600 gal/min (21,100 liters/min) and the comparable S&L aerator at 20,000 gal/min (75,000 liters/min).

After carefully reviewing the performance characteristics of both manufacturers' equipment, the Smith & Loveless aerator was selected largely

on the basis of its higher pumping capacity; its lower price (approximately $1,000 per unit); and the proximity of the manufacturer to the demonstration site. This last point was considered especially important for a demonstration project employing a relatively new and unique concept, although it should not normally preclude consideration of other potentially acceptable units.

SECTION VI

SYSTEM OPERATION AND ECONOMICS

OPERATING RESULTS

The most significant result of the operation of the demonstration waste treatment plant over a 2-year period was its clean, dependable, odor-free operation, conducted without interfering with the normal farm procedures. It has provided complete environmental control at nominal cost and with no inconvenience to the farmer-operator.

Treatment efficiency, important when wastes are discharged into receiving waters, has little significance in this case. Nothing is discharged to the environment except the harmless gases (chiefly ammonia and carbon dioxide) generated by the biological reactions in the aeration tank. Solids are retained in the settling basin, drying to an inert, odorless granular consistency having no particularly objectionable characteristics and suitable for land disposal. Liquids simply evaporate. Should the settling basin fill because of unusual amounts of rainfall, another pond will be built and used until the first one dries out. In terms of overall environmental effects, therefore, the treatment efficiency is 100%.

Table 2 shows the characteristics of the raw swine wastes being accommodated by the treatment system. Over the 14-week life span of a hog on the feeding floor, the 5-day BOD averages just over 150,000 mg/liter; the COD is 264,000 mg/liter; and the total nitrogen content averages 18,000 mg/liter.

The next table (Table 3) summarizes the effectiveness of the treatment process over the hogs' life cycle, as they grow from about 30 lb to over 200 lb (14 kg to 91 kg), with corresponding increases in their production of manure. As shown in Table 3, BOD_5 reduction averaged 96.4%; 91.7% of the COD was removed; suspended solids were reduced by 89.3%; and 89.6% of the total nitrogen was dissipated.

In terms of conventionally measured treatment efficiency, then, this system operates at a level comparable to the best, most expensive, modern, sophisticated treatment plants.

Table 2. RAW WASTE CHARACTERISTICS

	First 4 weeks (4/27-5/18)	Middle 6 weeks (5/25-6/29)	Last 4 weeks (7/6-7/27)	14-week average
BOD (5-day) (mg/liter)	109,500	175,700	160,500	152,500
COD (mg/liter)	263,100	233,600	309,500	263,800
Moisture content (%)	67.5	66.1	66.9	66.7
Ash (%, wet basis)	5.0	5.6	5.7	5.5
Organic nitrogen (mg/liter)	13,900	13,320	11,680	13,020
Ammonia nitrogen (mg/liter)	6,930	5,430	4,350	5,550
Total nitrogen (mg/liter)	20,830	18,750	16,030	18,570
Average hog weight (lb(kg))	50 (23)	100 (45)	175 (80)	110 (50)

Table 3. PERFORMANCE OF SWINE WASTE TREATMENT FACILITY AT SCHUSTER FARMS, GOWER, MISSOURI

	First 4 weeks (4/27-5/18)	Middle 6 weeks (5/25-6/29)	Last 4 weeks (7/6-7/27)	14-week average
Average hog weight (lb (kg))	50 (23)	100 (45)	175 (80)	110 (50)
BOD (5-day)				
influent (mg/liter)	21,695	50,538	64,125	46,400
effluent (mg/liter)	746	2,112	1,967	1,680
percent reduction	97.6	95.8	96.9	96.4
COD				
influent (mg/liter)	40,650	94,400	164,750	99,100
effluent (mg/liter)	5,250	7,358	12,453	8,210
percent reduction	87.1	92.2	92.4	91.7
Suspended solids				
influent (mg/liter)	42,025	80,542	102,520	75,800
effluent (mg/liter)	3,570	8,002	12,886	8,130
percent reduction	91.5	90.1	87.4	89.3
Total nitrogen				
influent (mg/liter)	5,124	6,618	8,616	6,760
effluent (mg/liter)	632	605	920	703
percent reduction	87.7	90.9	89.3	89.6

But, to once more emphasize the most important operational characteristics of the demonstration plant:

1. There is no objectionable odor; and

2. There is no pollutional discharge to the environment.

SYSTEM ECONOMICS

Construction of the aeration tank and purchase of the mechanical equipment account for the bulk of the capital outlay in a system of this type. The total plant investment for a comparable system should run about $12,000.

Electric power for the two 7.5 hp motors constitutes the major operating expense, totaling $2,445 annually at a rate of 2.5 cents per kilowatt hour. Electric rates will, of course, vary widely among different utilities and geographic areas.

Here is an approximation of the overall system economics:

Capital Costs:

Construction of Tank	$5,000
Equipment	
Aerators (2 at 7.5 hp)	4,600
Bridges	1,600
Wiring, tubing, etc.	800
Total	$12,000

Operating Costs:

Power--264 kwhr/day at 2.5 cents = $6.60/day or	$2,445/year
Maintenance and miscellaneous equipment	200
Amortization (12 years at 8%)	1,600
Total Annual Cost	$4,245/year or $11.62/day

Savings in Manure Handling

6 hr/week (one man plus one truck) at $5.00/hr = $30.00/week or $4.29/day

Net Cost:

$11.62 - $4.29 = $7.33/day

Time on feeding floor: 140 days
Weight gain: 195 lb/hog (88.5 kg/hog)

Net Waste Treatment Cost Based Upon Full Capacity of 1,000 Hogs:

$$\frac{\$7.33 \times 140}{1,000} = \$1.026/\text{hog, or roughly } \$1.00/\text{hog}$$

$$\frac{\$1.026}{195} = \$0.0053/\text{lb, } (\$0.00116/\text{kg}), \text{ or roughly 1/2 cent/lb}$$

These costs are believed to be within the limits of economic feasibility for most large swine producers, and the demonstration project can be generally considered a success from an economic as well as technical standpoint.

Profit margins in pork production hold the key to the acceptability to the producer of these costs and of the complete waste management concept. The $1.00/hog incremental cost of waste treatment may constitute a substantial percentage of the farmer's net profit. This additional cost must eventually be passed on to the consumer.

There is little doubt that society will pay for pollution control through higher costs at retail, but this is small comfort to the man currently confronted with making a capital investment. In other words, currently, as he markets his livestock, he will not find in the competitive market place that his pigs are worth one cent more for having been produced in a facility with zero runoff.

The initial impetus for construction of similar facilities, then, is likely to come from fear of urbanization, from fear of the neighbor's lawsuit, or from fear of a governmental agency.

Thus, the results of this demonstration offer a ready solution to the livestock man in trouble. Here is a system which can be adapted readily to variable terrain or livestock population. Waste material can be guttered or hauled to the tank, and dedication of land is minimal. Modification to existing facilities likewise is minimal. The demonstration and design, then, become practical, workable, and flexible--and perhaps most important, salable to the livestock man in trouble.

GENERAL APPLICATIONS OF THE SYSTEM

While the swine waste treatment plant described herein was specifically intended for the operation at Schuster Farms' Feeding Floor No. 7, it can easily be adapted to virtually any confined swine feeding operation.

The treatment plant itself--consisting of the aeration tank and the settling basin--will accommodate the wastes from approximately 1,000 feeder pigs, ranging in size from 30 lb (14 kg) to 225 lb (102 kg) and averaging 110 lb (50 kg).

Collection of the wastes is a separate function and must be adapted to a particular feeding operation. Gutters, sewers, conveyors, or trucks may constitute an appropriate means of transporting raw wastes to the treatment facility, depending on the local situation.

The aeration system demonstrated at Schuster Farms has proven itself more than adequate. Two 5-hp units would, in fact, probably provide sufficient aeration capacity for most 1,000-hog operations.

Table 4 shows the minimum aeration tank dimensions and aeration equipment specifications recommended for various hog populations. These are intended only as rules-of-thumb, based on a tank retention period of 30 days and a total waste flow of 1.5 gal/day/hog (5.7 liters/day/hog). Either fixed or floating aerators can be used equally well, but the manufacturer should be consulted regarding the best shape and type of aeration tank.

The settling pond into which the aeration tank discharge flows should be sized according to local rainfall/evaporation relationships. Properly sized, the pond will evaporate as much water as it receives. The pond should, in general, be from 3-5 ft (1-1.5 m) deep, allowing about 1 acre (0.4 hectare) of surface area per thousand hogs--less in dry areas, more in wet regions.

Table 4. MINIMUM RECOMMENDED TANK SIZE AND EQUIPMENT REQUIREMENTS FOR SWINE WASTE TREATMENT

Hog population	Aeration tank dimensions						Aeration equipment			
	Width		Length		Depth[a]		Number of units	Horsepower	Pumping capacity	
	ft	m	ft	m	ft	m			gpm	m^3/min
500	18	5.5	18	5.5	9.5	2.9	1	5.0	6,000	23
1,000	23	7.0	23	7.0	11.5	3.5	1	10.0	12,000	45
1,500	26	7.9	26	7.9	13.5	4.1	1	15.0	18,000	68
2,000	29	8.8	29	8.8	14.5	4.4	1	20.0	24,000	91
2,500	25	7.6	50	15.2	12.0	3.7	2	12.5	30,000	114
3,000	26	7.9	52	15.9	13.5	4.1	2	15.0	36,000	136
3,500	28	8.5	56	17.1	13.5	4.1	2	17.5	42,000	159
4,000	29	8.8	58	17.7	14.5	4.4	2	20.0	48,000	182
4,500	30	9.1	60	18.3	15.0	4.6	2	22.5	54,000	204

[a] Allow additional depth for freeboard, depending on equipment manufacturer's recommendations.

ESTIMATED COSTS FOR SYSTEMS OF VARIOUS SIZE

Aeration Tank

The estimated cost of constructing a reinforced concrete tank having the general specifications and features of the design given in the Appendix is

$$C = 500 + 0.4\ d^3 + 24\ d^2$$
$$(\ C = 500 + 14.1\ d^3 + 258\ d^2)$$

for a square tank, and

$$C = 500 + 0.8\ d^3 + 40\ d^2$$
$$(\ C = 500 + 28.3\ d^3 + 431\ d^2\ )$$

for a rectangular tank, where C = the cost in current (1973) dollars, and d = the liquid depth in feet (meters).

A 20 ft x 20 ft x 10 ft (6.1 m x 6.1 m x 3.1 m) tank, then, would cost $3,300 and a 20 ft x 40 ft x 10 ft (6.1 m x 12.2 m x 3.1 m) tank $5,300.

The depth (d) will be half the width; for rectangular tanks, the length will be twice the width.

Aeration Equipment

Surface mechanical aerators capable of doing the necessary job both in oxygen transfer and fluid pumping currently cost about $1,700 plus $170/hp, including controls. A 5-hp unit, then, would be expected to cost about $2,550; a 10-hp aerator, $3,400; and a 20-hp unit, about $5,100. Costs are essentially the same for bridge-mounted and floating aerators, the cost of a steel bridge being roughly comparable to a good flotation collar.

Operating Costs

The total annual cost of a waste treatment system of this type amounts roughly to the electric power cost plus 20% of the capital outlay (to allow for depreciation, interest, maintenance, etc.).

The power cost will be approximately $0.50/day/hp, with the electric rate at 2 cents per kilowatt-hour. For other rates, the cost would be directly proportional.

SECTION VII

APPENDIX

The Appendix covers the construction details of the reinforced concrete aeration tank installed at Schuster Farms' demonstration site. As already described, it will accommodate the wastes from 1,000 feeder pigs, ranging in size from 30 to 225 lb (14 to 102 kg).

It must be emphasized, however, that the aeration tank described here was designed specifically for the Smith & Loveless aerators; different tank configurations may be required for other units, and manufacturers should be consulted regarding the optimum tank shapes and dimensions for their equipment.

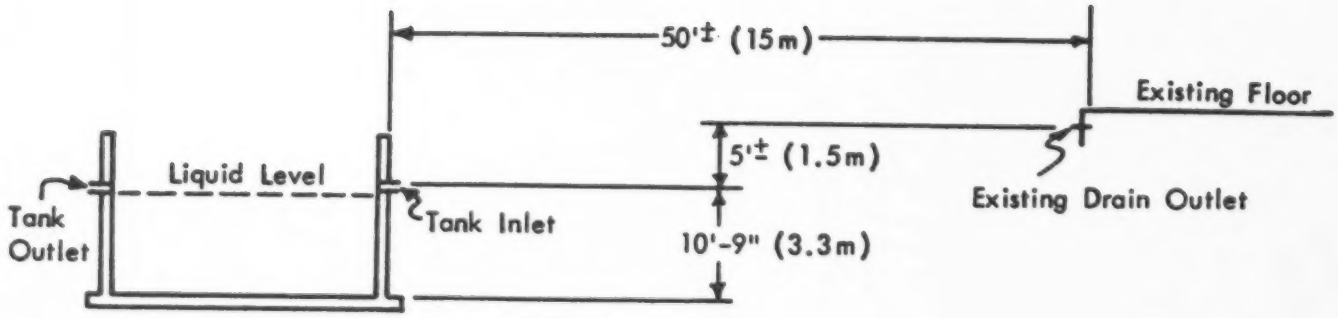
THE AERATION TANK

Figure A-1 is an elevation view of the tank installation at Schuster Farms' Feeding Floor No. 7. The tank is located 50 ft (15 m) west of the west end of the feeding floor, connected by tile drain pipe. The slope of the drain is about 5 ft in 50 ft, or 1 in 10. This slope provides adequate velocity for hydraulic transport of the manure and other wastes.

Figure A-2 is a perspective and sectional view of the tank. The tank installed at the demonstration site also has a concrete beam across its width at the center, connecting the two long walls for additional support; this is not really necessary, but after the mishap with the concrete block walls, no chances were taken.

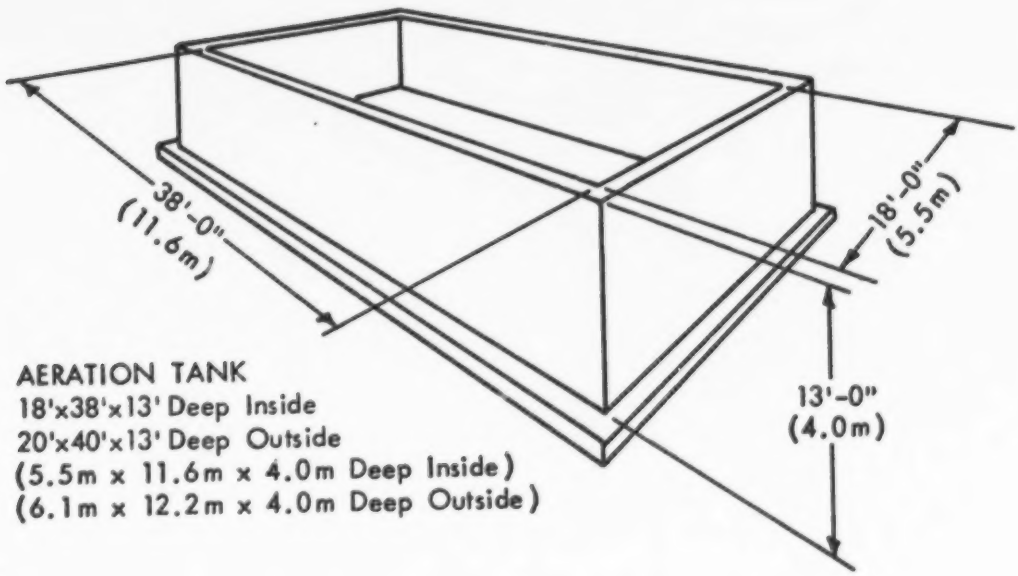
Figure A-3 is a sectional view of the tank, locating the inlet and outlet. The outlet height must be determined experimentally, since the aerators push large volumes of water toward the sides. An adjustable outlet structure is therefore recommended, so that the liquid level can be kept at the top of the rotor blades when the equipment is operating.

Figure A-4 is a plan view of the tank and a logitudinal section. Figure A-5 covers the reinforcing details and shows how the tank walls should be keyed into the floor slab.

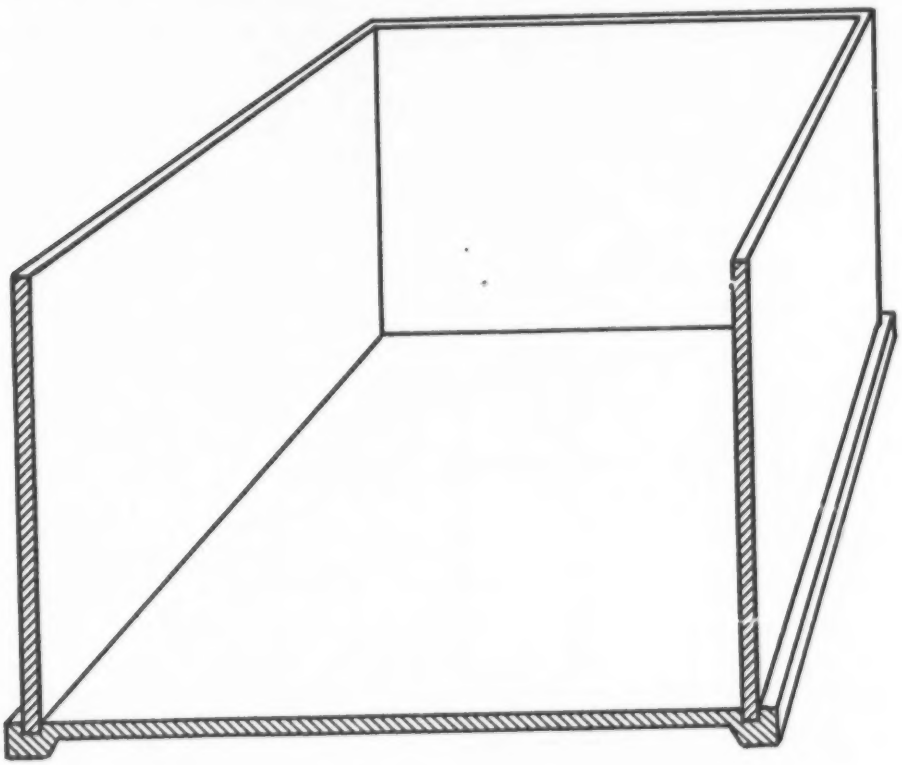


ELEVATION VIEW

Figure A-1 - Location of aeration tank with respect to existing facilities

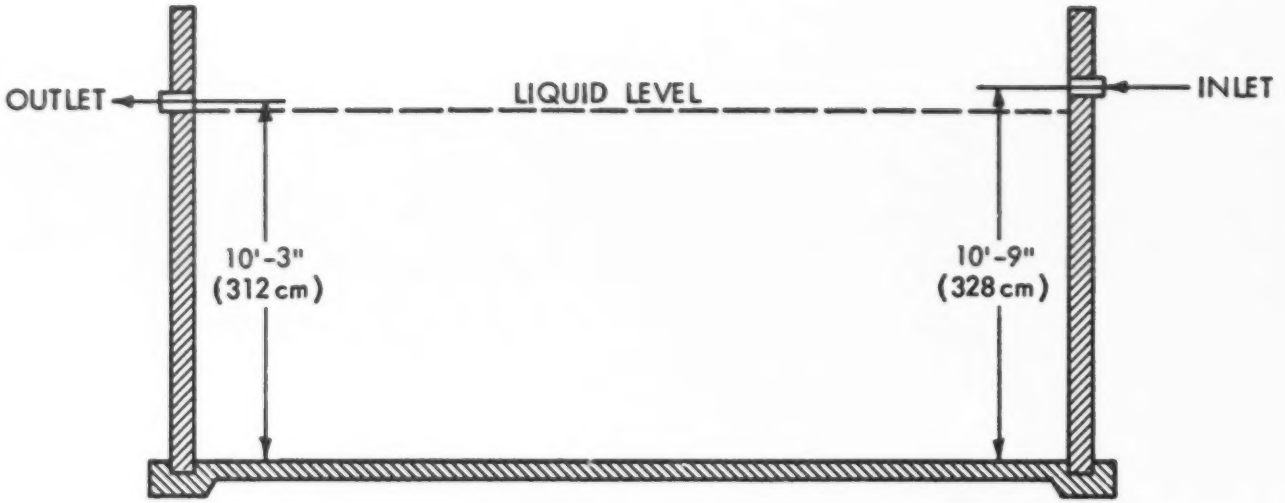


AERATION TANK
18'x38'x13' Deep Inside
20'x40'x13' Deep Outside
(5.5m x 11.6m x 4.0m Deep Inside)
(6.1m x 12.2m x 4.0m Deep Outside)



SECTION THROUGH TANK

Figure A-2 - General configuration of aeration tank



INLET & OUTLET: 6" (15.2 cm) Set at Center of Long
(40'; 12.2 m) Sides at Heights Shown

Figure A-3 - Location of aeration tank inlet and outlet

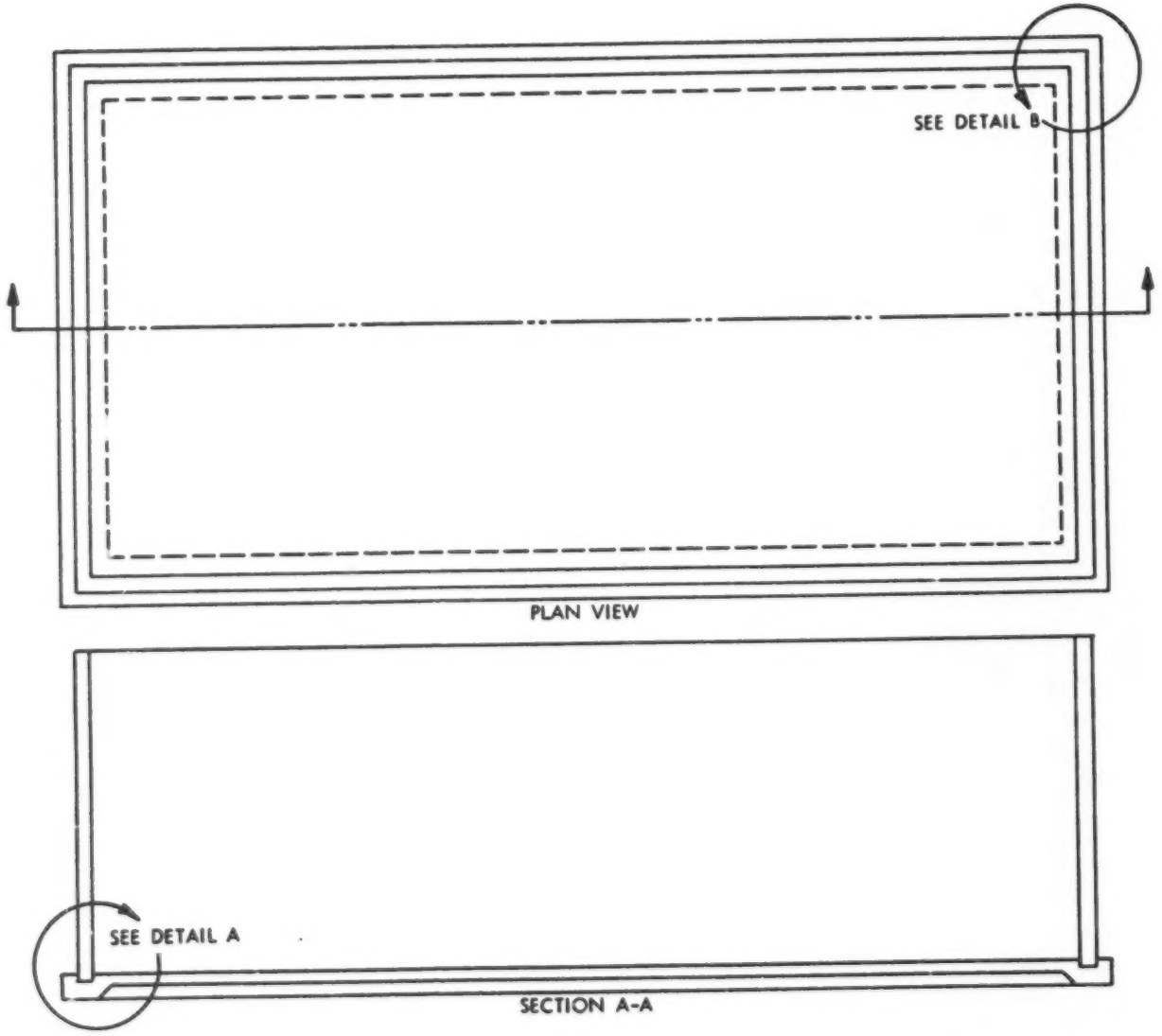
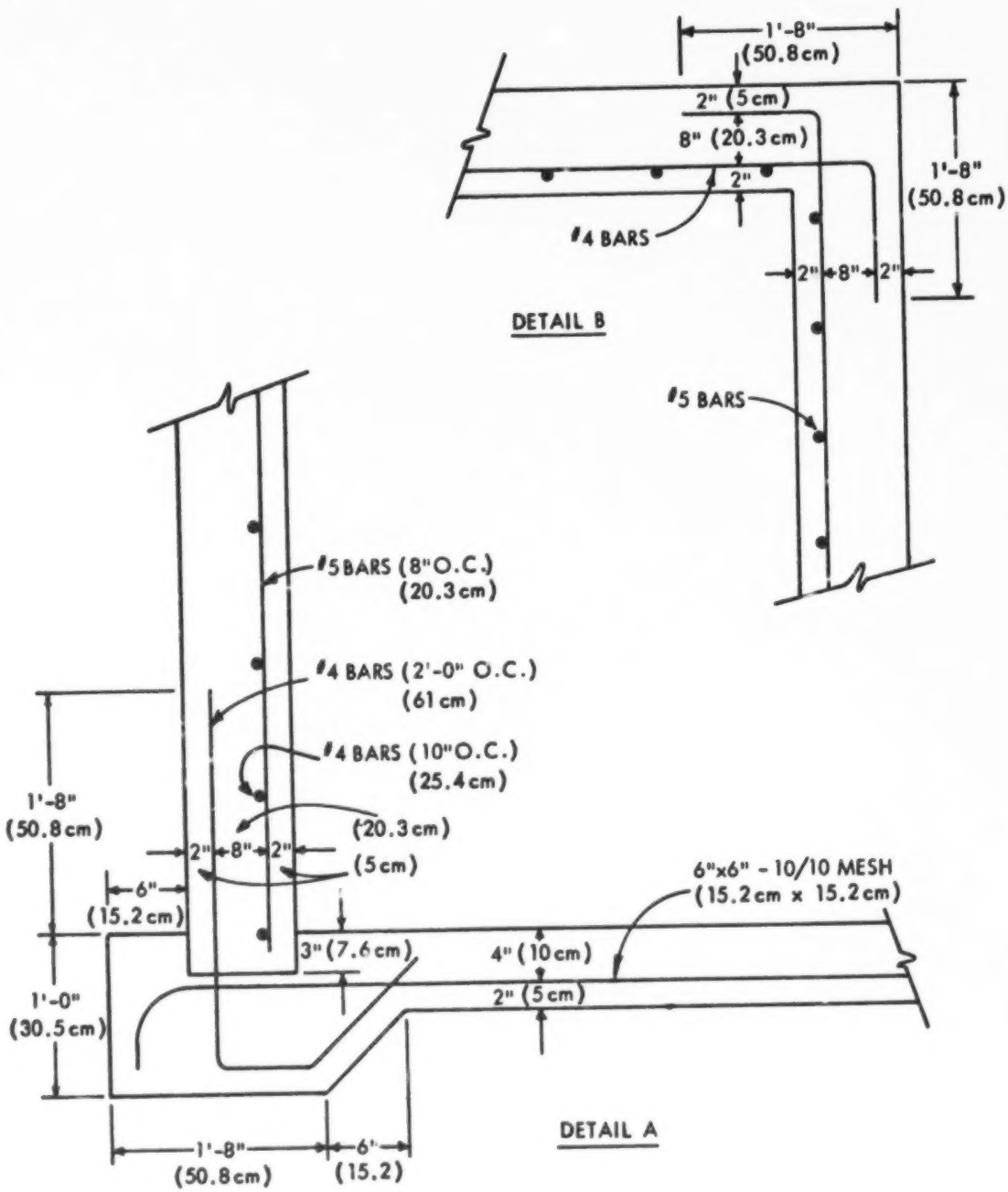


Figure A-4 - Plan view and section of aeration tank



REINFORCING DETAILS

Figure A-5 - Aeration tank reinforcing details